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ABSTRACT

The first volume of a 700-page, two-volume study presents a basic background of U.S. science policy and describes research and development in the public and private sectors, university research, the diffusion of technology in the U.S., and important issues in American research and development. This publication arose from efforts of two U.S. members of a cooperative research working group under the USA/USSR Joint Commission of Scientific and Technical Cooperation which compared major science policies of the two countries in the planning and management of research and development. (CS)

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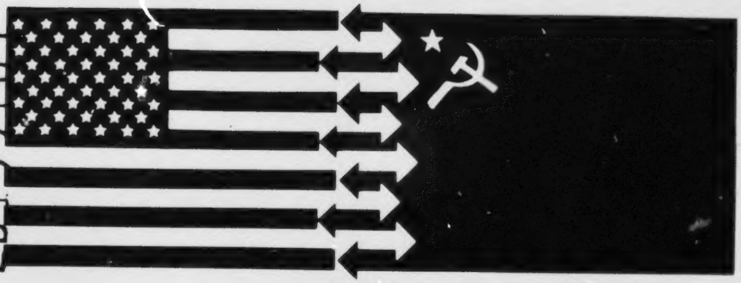

Science Policy: USA / USSR

Volume I: Science Policy in the United States

Report prepared for National Science Foundation
Directorate for Scientific, Technological and International Affairs
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U S DEPARTMENT OF HEALTH
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SCIENCE POLICY: USA/USSR

Volume I

Science Policy in the United States

Nat C. Robertson

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INTRODUCTION

Beginning in 1972 the Governments of the United States of America and the Union of Soviet Socialist Republics signed a series of bilateral agreements for cooperation in various areas of science and technology, of which there are now eleven in number. The senior of these, the Agreement on Cooperation in Fields of Science and Technology, was signed by President Nixon and General Secretary Brezhnev in May 1972 and is implemented through a U.S.-U.S.S.R. Joint Commission on Scientific and Technical Cooperation, chaired on the U.S. Side by the President's Science and Technology Advisor. One of the twelve active Working Groups carrying out cooperative research under the Joint Commission is in the area of Science Policy, which in turn focuses on two major areas of mutual interest: the Planning and Management of Research and Development, and Fundamental Research Systems.

The present two-volume study, Science Policy: USA/USSR, prepared by members of the U.S. side of the working group, is based on the first phase of work in Science Policy by the group concerned with R&D Planning and Management,[1] which lasted from approximately 1973 to 1977. The goal of this phase was to build a base of information which could then serve to orient U.S. participants to more discrete and sophisticated analyses of the policy-making systems in the respective countries concerned with scientific and technical research; the principal mode of operation during this phase was exchange of visits, written information, reports, and specific questions and answers between the U.S. and Soviet members of the group. It became quickly apparent, although not to anyone's great surprise, that there would be a number of problems in emerging with satisfactory products, from information access and administrative difficulties to, perhaps most significantly, entirely different perceptions of the content of the study of science policy, incompatible terminology, and divergent analytical traditions, not to mention the important substantative differences in the making of science policy in the two countries. In many senses, we were speaking entirely different languages to one another and for this reason our initial progress was often slow and painful.

By 1976-1977, however, enough progress had been made to encourage U.S. participants to think about compiling what we had learned, both about ourselves and the Soviet Union, into monograph form in order to make this information accessible to the public at large. Again, not surprisingly, the job of compilation was beset by many of the same difficulties mentioned above. An initial summary prepared by Battelle Columbus Laboratories was reviewed and commented upon by U.S. participants, after which Mr. Nat C. Robertson, a distinguished technical administrator and research scientist with broad experience in the U.S. industrial sector, and Dr. Paul M. Cocks, a leading specialist on science policy in the U.S.S.R., utilized the data prepared by Battelle in writing the present volumes. The results, I believe, merit close examination by scholars, scientists, government and industrial officials, and the lay public.

The time and effort of an unusually large number of individuals went into vaious phases of this project. Nat Robertson and Paul Cocks deserve special praise for taking on the extremely challenging task of sifting through the mass of accumulated material, verifying data, and integrating it with their own expert knowledge to yield an intelligent and illuminating final product. The initial summary by Battelle Columbus Laboratories was, of course, highly instrumental in getting the study off the ground and the contributions of the Battelle staff are gratefully acknowledged. The information contained in the volume on the U.S.S.R. could not have been obtained in the first place were it not for the enthusiastic participation--which was severely tested at times--by the U.S. members of the Science Policy Working Group, most particularly its former U.S. Chairman, Dr. David Z. Beckler, and of the members of the Subgroup on R&D Planning and Management who participated in the project's first phase (in alphabetical order), Joseph Berliner, Lewis M. Branscomb, Paul M. Cocks, Murray Feshbach, Richard T. Gray, Herbert Levine, Franklin A. Long, Nat C. Robertson, Lowell W. Steele, and Robert L. Stern. The staff of the Arlington, Virginia office of SRI International assisted with the final editing and preparation of the manuscript. Although these studies are not official publications of the U.S. side of the working group and only their authors are responsible for their content, I wish to take this opportunity to thank all those who assisted in their preparation. Financial support for the project was provided through the National Science Foundation.

William D. Carey
U.S. Chairman, U.S.-U.S.S.R. Working
Group on Science Policy

June 1980

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[1] Until 1979 there were four subgroups of the Science Policy Working Group: R&D Planning and Management, R&D Financing, Training and Management of S&T Manpower, and Systems for Stimulating the Development of Fundamental Research. Other publications resulting from the Working Group's efforts include Louvan E. Nolting and Murray Feshbach, "R&D Employment in the U.S.S.R.," Science, v. 207 (February 1, 1980), pp. 493-503; and Systems for Stimulating the Development of Fundamental Research (Report prepared by the U.S.-U.S.S.R. Working Subgroup on Systems for Stimulating the Development of Fundamental Research of the National Academy of Sciences/National Research Council), NTIS Order Number PB80-162316.

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In the preparation of this volume, I wish to acknowledge the assistance of Mr. Richard S. Morse, retired president of the M.I.T. Development Foundation and formerly Assistant Secretary of the Army for Research and Development; Dr. Charles N. Kimball, Chairman of the Midwest Research Institute; Dr. L.F. Barrington of the Office of Technology Assessment, U.S. Congress; and Professor David F. Ollis of the Department of Chemical Engineering, Princeton University.

The Battelle authors made extensive use of the answers prepared by the U.S. working group to questions addressed to us by the Soviet side. I have retained most of this material, but have shortened a number of the sections. On the other hand, I have made somewhat greater use of the case studies prepared for our working group by outside organizations.

I have added a limited amount of new material in order to provide a more comprehensive view of management practices in applied research and technology in the United States, in order to make the report more useful to active R&D managers in other countries.

I hope this report will prove useful to students and practitioners of applied research in the U.S. and in other countries.

N.C. Robertson
July 7, 1980

I BACKGROUND AND APPROACH TO SCIENCE POLICY

IN THE UNITED STATES

TECHNOLOGY IN THE AMERICAN SYSTEM

The desire to foster technological invention has deep roots in the American system. Such invention is expected to contribute to economic growth and to improve the standard of living of the U.S. citizen. Article I of the Constitution of the United States gives Congress the power "to promote the progress of science and the useful arts by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." That section (section 8), providing the Constitutional basis for the patent system, reflects two essential premises of the American system: the idea of human progress through science and technology, and the theory of "natural rights" that holds that each person has the right to own property. From these premises the American system has developed. Understanding them assists one in better understanding the present structure and functioning of R&D in America.

One particular consequence, for example, is that in America inventors and practical innovators have achieved greater status and respect than pure scientists. American school children know well the accomplishments of such people as Benjamin Franklin, Thomas A. Edison, and Eli Whitney. They may know little about Joseph Henry, Benjamin Silliman, or Louis Agassiz. Thus American society has not suffered from some problems common in those Western European societies who value the engineer and applied scientist less highly than the individual engaged in basic research.

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SCIENCE POLICY ENVIRONMENT

The objective of the government in the United States is to provide a climate in which these innovators perceive economic or social returns from research and development. Innovation, it is believed, cannot be administered. American science policy has never been deliberately planned. There is no one agency charged with determining science policy, no one clearinghouse for scientific and technical (S&T) information. Instead, the American system is highly diversified, pluralistic, pragmatic. And it is dynamic. Its current state, as described in this report, will not persist long. The government's role is that of a catalyst, establishing not policies but major purposes --such as national security, improvement of health science, development of energy and natural resources--and helping to shape an environment in which these purposes can be achieved.

That science policy environment, all sectors agree, must include the following elements.

The first element, as we have seen, is the patent policy, a powerful stimulus to innovation in the United States.

A second element is the freedom to pursue academic research. This is linked, third, to a strong system of higher education and training, based on freedom of career choices. The government has strongly supported vocational and scientific education. Expansionary or restrictive government budgets accelerate or decelerate the levels of academic research and training.

Fourth, healthy R&D requires an active, competitive enterprise system, with incentives and rewards for innovation. This competitive spirit is found at all levels in the government, in universities, and in the private sector. In particular it is seen among researchers eager for subsidies, among university institutes or industrial laboratories seeking federal contracts, among government agencies wanting higher priorities and increased resources for their own missions.

A fifth element is reliance on the market mechanism to generate technological entrepreneurship.

Sixth, the government usually serves as a gap-filler and an occasional aggregator of needs and demands rather than as the primary stimulator of science. The federal government has, however, been the major driving force in financing R&D, while the private sector, including industry, universities, and not-for-profit institutions, has been the major performer. Industry often performs and applies R&D, to a significant extent, in anticipation of government standards and regulations. Science policy has been indirectly formulated by the federal government and implemented through a division of labor between public and private institutions. The federal government financed about 53 percent and performed 16 percent of the nation's R&D work in 1977, while the private sector financed about 47 percent and performed 84 percent of the work (Table 2-1). This reflects a fundamental political choice made during World War II: the government prefers to assign to private industry and the universities the major role in performing research and deliberately to avoid the creation of specialized public institutions for this purpose. The government works largely indirectly.

Seventh, however, the government is required to undertake directly those constitutional or statutory responsibilities--national defense, public health, development of nuclear energy--which are uniquely governmental and for which the market forces are unsuited. Such developments in both time and scope exceed private sector incentives and financial capabilities. Sometimes, as in agriculture, the small scale of the individual practitioner precludes private investment in R&D. Another example is the direct federal support--through, for example, the National Science Foundation (NSF)--of basic research. The federal government is the primary sponsor of work to provide the broad scientific and educational base required for the entire range of technological advances on which society depends. Private firms could not capture the social benefits produced on a time scale consistent with commercial requirements.

These are some basic features of the science policy environment in the United States. The mechanisms for achieving a climate favorable to science and its applications are discussed in detail in the following chapters, beginning with a discussion of planning and management in the federal and state governments and moving on to the universities and the private sector. A final chapter highlights important issues and trends in American R&D in general.

II THE ORGANIZATION OF R&D:

THE PUBLIC SECTOR

THE FEDERAL GOVERNMENT

The administration of scientific matters in the United States conforms to the highly decentralized organization of the federal government. In the Executive Branch there are over 40 agencies and departments--including the Executive Office of the President--directly concerned with science policy. Scientific matters are the primary interest, however, of only 6 such groups (see Table 3-1). The Legislative Branch (the Congress, composed of the Senate and the House of Representatives) has over 20 committees and other bodies directly or indirectly involved in scientific activities (see Table 3-2).

This plurality of groups, added to a number of historical factors, militates against any overall plan for managing science policy. The Executive Branch and the Legislature work separately. Their concerns have not always been identical; their priorities are sometimes in conflict. Science policy is thus not a grand design deliberately established but the meeting point of a complex of different wills, both within the Executive Branch and in Congress. This section describes the policy-making structure of the Executive Branch and the Legislature as it bears on scientific matters.

The Executive Branch

The Executive Branch consists of the President and his immediate staff (the Executive Office); the Secretaries of the 16 Departments, who are Cabinet officers appointed by the President and confirmed

TABLE 2-1

ORGANIZATION OF THE EXECUTIVE BRANCH OF THE U.S. GOVERNMENT FOR SCIENTIFIC ACTIVITIES

THE EXECUTIVE BRANCH

Mainly Scientific Activities

- Energy Resources Council
- Federal Energy Administration
- National Aeronautics and Space Administration
- National Science Foundation
- Office of Science and Technology Policy
- President's Committee on Science and Technology

Partially Scientific Activities

- ACTION
- Appalachian Regional Commission
- Central Intelligence Agency
- Civil Aeronautics Board
- Consumer Product Safety Commission
- Council of Economic Advisors
- Council on Environmental Quality
- Department of Agriculture
- Department of the Air Force
- Department of the Army
- Department of Defense
- Department of Defense Agencies and Joint Service Schools
- Department of Energy
- Department of Health, Education, and Welfare
- Department of Housing and Urban Development
- Department of the Interior
- Department of Justice
- Department of Labor

TABLE 2-1 (Continued)

Department of the Navy
Department of State
Department of Transportation
Department of Treasury
Environmental Protection Agency
Federal Communications Commission
Federal Power Commission
Federal Reserve System
Federal Trade Commission
General Services Administration
Inter-American Foundation
Interstate Commerce Commission
National Security Council
Occupational Safety and Health Review Commission
Office of Drug Abuse Policy
Office of Management and Budget
Office of Telecommunications Policy
Overseas Private Investment Corporation
President's Commission on Mental Health
Securities and Exchange Commission
Small Business Administration
Smithsonian, The
Tennessee Valley Authority
United States Arms Control and Disarmament Agency
United States Civil Service Commission
United States Information Agency
United States International Trade Commission
United States Postal Service
Veterans Administration
White House, The

TABLE 2-1 (Continued)

Mainly Non-Scientific Activities

Administrative Conference of the United States
American Battle Monuments Commission
American Revolution Bicentennial Administration
Canal Zone Government
Commission of Fine Arts
Commission on Civil Rights
Commodity Futures Trading Commission
Community Services Administration
Council on Wage and Price Stability
Domestic Council
Equal Employment Opportunity Commission
Export-Import Bank of the United States
Farm Credit Administration
Federal Deposit Insurance Corporation
Federal Election Commission
Federal Home Loan Bank Board
Federal Maritime Commission
Federal Mediation and Conciliation Service
Federal Property Council
Foreign Claims Settlement Commission of the United States
Indian Claims Commission
National Credit Union Administration
National Foundation on the Arts and the Humanities
National Labor Relations Board
National Mediation Board
Office of the Special Representative for Trade Negotiations
Panama Canal Company
Pension Benefit Guaranty Corporation
Postal Rate Commission

TABLE 2-1 (Continued)

Railroad Retirement Board
Renegotiation Board
Selective Service System

TABLE 2-2

CONGRESS AND SCIENCE

SENATE

Mainly Scientific Activities

- Energy and Natural Resources

Partially Scientific Activities

- Agriculture, Nutrition, and Forestry
- Appropriations
- Armed Services
- Budget
- Commerce, Science, and Transportation
- Environment and Public Works
- Foreign Relations
- Human Resources

No Scientific Activity

- Banking, Housing and Urban Affairs
- Finance
- Government Affairs
- Judiciary
- Rules and Administration
- Veterans Affairs

HOUSE OF REPRESENTATIVES (Standing Committees)

Mainly Scientific Activities

- Science and Technology

Partially Scientific Activities

- Agriculture
- Appropriations

TABLE 2-2 (Continued)

Armed Services
Budget
Education and Labor
Government Operations
House Administration
Interior and Insular Affairs
International Relations
Interstate and Foreign Commerce
Merchant Marine and Fisheries
Public Works and Transportation
Small Business
Ways and Means

No Scientific Activity

Banking, Finance, and Urban Affairs
District of Columbia
Judiciary
Post Office and Civil Service
Rules
Standards of Official Conduct
Veterans Affairs

JOINT COMMITTEES

Mainly Scientific Activities

Joint Committee on Atomic Energy
Migratory Bird Conservation Commission

Partially Scientific Activities

Board of International Broadcasting
Commission on Security and Cooperation in Europe
Consumer Product Safety Commission
Environmental Study Conference
Joint Economic Committee

TABLE 2-2 (Continued)

National Commission on Electronic Fund Transfers
National Transportation Policy Study Commission
President's Committee on Mental Retardation

No Scientific Activity

American Indian Policy Review Commission
Commission for Extension of the United States Capitol
Commission on Administrative Review
Commission on Art and Antiquities of the U.S. Senate
Commission on Federal Paperwork
District of Columbia Law Revision Commission
Franklin Delano Roosevelt Memorial Commission
House Commission on Congressional Mailing
House Office Building Commission
Japan-United States Friendship Commission
Joint Committee on Congressional Operations
Joint Committee on Defense Production
Joint Committee on the Library
Joint Committee on Printing
Joint Committee on Taxation
Marine Corps Memorial Commission
National Commission for Manpower Policy
Permanent Committee for the Oliver Wendell Holmes Devise Fund
Privacy Protection Study Commission
Senate Office Building Commission
Temporary Commission on Financial Oversight of the District of Columbia

TABLE 2-2 (Continued)

The Interparliamentary Union

OTHER OFFICIALS

Mainly Scientific Activities

- Botanic Garden
- Office of Technology Assessment

Partially Scientific Activities

- Congressional Budget Office
- General Accounting Office
- Library of Congress Congressional Research Service

No Scientific Activity

- Government Printing Office

by the Senate; and heads of various commissions and agencies. One responsibility of the President "is to ensure that science and technology are used most effectively in the interests of national security and the general welfare."[1] To exercise this responsibility the President relies on a growing number of agencies and services in the Executive Office that are directly concerned with science policy.

The President's role consists of settling problems drawn to his attention, including those of political or social tension among competing congressional, scientific, university, or industrial groups involved in R&D. He may also decide on research questions to ensure consistency among the various agencies, to assure expenditures for a long-term administrative activity, to undertake programs of foreign aid or international cooperation, or to create a new authority combining the dispersed activities of existing agencies into a single unit with wider responsibilities (such an act generally requires Congressional approval). The President sets the broad lines of the national R&D effort and Congress pronounces upon them, approving, rejecting, or modifying the President's policy. These lines are presented in the annual budget proposed by the President. It is in the budgeting process that priorities are negotiated and established, as is indicated in the discussion of the Office of Management and Budget (OMB) that follows.

Although earlier Presidents had sought advice on important technical matters from prominent scientists, notably President Roosevelt from Vannevar Bush during World War II, President Eisenhower was the first to designate an official Science Advisor when he appointed James Killian of MIT in 1957. All but one of the Science Advisors have had university backgrounds. The office was allowed to lapse for a period under Presidents Nixon and Ford.

These Science Advisors and the groups they have chaired, such as the President's Science Advisory Council (PSAC) through Nixon's first term and the more recent Committee on Science and Technology, have not been intended to plan and administer the national R&D enterprise. They have not blueprinted the nation's R&D goals, activities, or performance. In fact, they have covered only a limited portion of that spectrum.[2] PSAC essentially carried out project analysis. It did not formulate policy, but responded to problems. The Science Advisor's chief role has been to help in clarifying the government's choices in allocating resources to technological investment for defense, space, and other governmental responsibilities.

The President also receives advice, both formally and informally, from his immediate staff and the heads of various agencies. His staff includes some highly skilled scientists and engineers; others are available to advise the President outside the normal administrative machinery. Although the President is directly involved only occasionally in science issues, his office is more frequently involved. The President, however, does sometimes report to the nation on science and technology in Presidential messages, and he awards National Medals of Science which indirectly promote science. Several special groups within the Executive Office that are important in shaping science policy are described here. Their mechanisms for managing R&D are detailed later in this chapter.

Science Policy Groups in the Executive Office

The National Security Council (NSC) brings together leaders of agencies associated with national defense and is under the direct authority of the President. The Council is at the same time a coordinating and an advisory body where major political and strategic questions are discussed--including questions which frequently have important scientific and technical implications.[3]

The Council of Economic Advisors (CEA) compiles data which enable the President to know the economic factors involved as he formulates national policy. Each year it prepares a Report on the Economy, which the President presents to Congress. Surprisingly, comments on the scientific and technological effort are generally absent.[4]

The Office of Management and Budget (OMB) is more involved in scientific affairs than the NSC and CEA. Its primary task is to prepare the budget document which the President submits to Congress in the name of the whole administration. Thus OMB helps the President carry out his purposes and works closely with him. The Office intervenes in three stages of the process of preparing legislation. First, it examines all legislative proposals before an agency or administration can submit them for Congressional approval. Second, it also often approves answers given by the agencies to the questions of Congressional committees. Finally, OMB briefs the President when enactments are presented to him for his signature or veto. These responsibilities make the OMB the most firmly established instrument used by the President in executing his major coordination tasks.

OMB also performs other tasks. It briefs the President on any executive orders he may contemplate.[5] It studies possible improvements both in the general organization of the administration and in its operating procedures. And it consolidates the budget requests of federal agencies into the single President's Budget on which Congress has to decide.[6]

The budget process gives OMB considerable influence in government research. The value of the programs proposed by agencies can be regularly reassessed and their shortcomings pointed out. Because OMB works with the whole administration, it can coordinate different undertakings. These broad possibilities, however, are circumscribed by the difficulties of the task.[7]

OMB is often criticized for not assembling a highly competent cadre of experts in its own organization who can provide the skills required to carry out the planning and funding of science and technology. OMB has elected to do without the scientific skills which would enable it to examine in depth the merits of applications for R&D funds. This activity would tend to divert the Office from its primary responsibilities. The limitations of this renunciation, however, must not be exaggerated. Considerable specialization has emerged within OMB; for when someone is daily concerned with the activity of a particular agency, one gradually acquires, even without formal training, an unusually sound knowledge and understanding of most of the problems which arise.

Three other groups in the Executive Office are directly concerned with scientific affairs. Each of these performs its duties in support of the President. The Office of Science and Technology Policy (STP) was established in May 1976 by the National Science and Technology Policy, Organization, and Priorities Act. The Act provides for the Office to advise the President of scientific and technological considerations in such areas of national concern as the economy, national security, health, foreign relations, and the environment; to evaluate the scale, quality, and effectiveness of the federal effort in science and technology; to provide advice and assistance to the President, OMB, and federal agencies throughout the federal budget development process; and to assist the Peesident in providing leadership and coordination of the R&D programs in the federal government.[8] Although it may look like a centralized policy-making agency, OSTP is not. Its chief role is to provide information to the President on science and engineering issues and clarify the government's choices in allocating resources. The specific functions within that role are a matter of much debate.

The Director of OSTP is the President's Science Advisor and also chairs the Federal Coordination Council for Science, Engineering, and Technology (FCCSET). In addition, the council is composed of one representative of each of the following federal agencies: Department of Agriculture; Department of Commerce; Department of Defense; Department of Health, Education, and Welfare; Department of Housing and Urban Development; Department of the Interior; Department of State; Department of Transportation; Veterans Administration; National Aeronautics and Space Administration; NSF; Environmental Protection Agency; and Energy Research and Development Administration.

The FCCSET considers problems and developments in science, engineering, and technology and related activities affecting more than one federal agency and recommends policies and other measures designed to:

1. Provide more effective planning and administration of federal scientific, engineering, and technological programs
2. Identify research needs including areas requiring additional emphasis
3. Achieve more effective use of the scientific, engineering, and technological resources and facilities of federal agencies, including the elimination of unwarranted duplication
4. Further international cooperation in science, engineering and technology[9].

In addition, the FCCSET is responsible for performing related advisory duties as requested by the President.

The Intergovernmental Science, Engineering and Technology Advisory Panel (ISETAP), also chaired by the Director of OSTP, was created in November 1976 to act as a liaison between state and local governments and the scientific research community. The members of ISETAP are state and local legislators, including a number of governors, who make up five ISETAP task forces. These task forces identify areas of application for science and technology at the level of state and local government, and attempt to coordinate these potential applications with the available resources.

Executive Departments and Other Organizations of the Executive Branch

More than 15 departments, administrations, agencies, and commissions share varying degrees of interest and responsibilities for scientific policy and activities. Most departmental secretaries have a policy level assistant secretary for science and technology. Some of these serve primarily in a staff capacity providing policy and program guidance and helping to frame and defend the departmental R&D budget within the department, before OMB, and before the Congressional committees overseeing the department's programs and budgets. Others, such as the Assistant Secretary of the Navy and Assistant Secretary of Commerce, have major line responsibilities. Below the assistant secretaries responsible for R&D, organizational patterns vary, each agency having a unique organizational structure reflecting its individual mission and legislative mandates. R&D is carried out by in-house laboratories and by contracts with industrial firms and the universities, with the preponderance of R&D performed by outside organizations (see later section and chapter 4). Sufficient scientific and technical strength should be maintained within the management of the departments and agencies to direct, monitor, and evaluate R&D performance.[10] The departments and agencies draw on expert consultants from industry and the universities as individuals and as members of advisory panels attached to the departments and agencies.

R&D programs of the several departments and agencies are coordinated through the budget process and through FCCSET. Several of the more important of these influencing R&D are described in the following section.

The Department of Defense (DOD) controls and administers more funds for R&D than any other agency of the federal government. The Department provides the military forces needed to deter war and protect the security of the country. In this role, DOD has developed hardware and techniques necessary to carry out the defense task.

DOD fosters R&D both by contract with industry and universities and by maintenance of government-operated facilities. Within DOD the ultimate responsibility for R&D centers in the Office of the Secretary of Defense. Within the Office of the Secretary is the Undersecretary of Defense for Research and Engineering.

The sponsorship and conduct of research are highly dispersed throughout the Department. Its programs range from basic science through hardware development to the development of better procedures for organizing, managing, and controlling R&D.

The National Aeronautics and Space Administration (NASA) assembles and disseminates information on space exploration and carries out large R&D programs. For the last purpose, NASA uses installations and laboratories which it administers directly through forecasting, programming, and control services. These also coordinate the R&D activities assigned to private institutions. The Administration conducts some research programs in its own laboratories, but almost 90 percent of its R&D is conducted through contracts with industrial, university, and other contractors. In this respect, NASA's functioning closely parallels that of DOD; in fact, both use similar contracting and administrative procedures.

In the act establishing NASA, one responsibility was defined as "the progress of human knowledge on the phenomenon of the atmosphere and space." Thus NASA conducts both applied and basic research.

Many departments and agencies of the federal government have researched sources of energy. In 1974, the Energy Research and Development Administration (ERDA) was established to reorganize and consolidate federal activities relating to energy. Its goals were to develop and increase the efficiency and reliability of the use of all energy sources; to increase the productivity of the national economy and strengthen its position in international trade; to make the nation self-sufficient in energy; to restore, protect, and enhance environmental quality; and to assure public health and safety.[11] ERDA consolidated functions of the Department of Interior in coal research, energy research centers, and underground electric power transmission research; functions of NSF in solar, geothermal, and other research; functions of the Environmental Protection Agency in alternative automotive power systems; and the military and production activities and nuclear research and development activities of the Atomic Energy Commission.

In 1977 a new Department of Energy (DOE) was established at Cabinet level and the functions of ERDA were transferred to it. DOE is expected to encourage and conduct R&D, including demonstration of commercial feasibility and practical applications of the extraction, conversion, storage, transmission, and utilization phases in the use of energy from fossil, nuclear, solar, geothermal, and other energy sources. It encourages and participates in international cooperation in energy and related environmental R&D.[12]

The Department of Health, Education, and Welfare (HEW) controls and administers one of the largest R&D budgets of the federal government. Pursuit of the physical, medical and social well being of man has led the Department to carry out important research in health and education.

HEW provides seven essential services:

1. The Public Health Service, which includes the National Institutes of Health (NIH), engages in medical research, health and hygiene in both the United States and developing countries

2. The Department of Education formulates and coordinates education policy and related activities

3. The Social Security Administration carries out general economic and social research related to its overall responsibilities for assistance to the elderly

4. The Food and Drug Administration, concerned mainly with protecting the public, carries out research programs as required by its inspection duties

5. The Vocational Rehabilitation Administration, Saint Elizabeth's Hospital; and the Welfare Administration.[13]

The Department of Agriculture (USDA) works to improve and maintain farm income, to develop and expand markets abroad for agricultural products, and to curb and to cure poverty, hunger and malnutrition at home. It enhances the environment and maintains our production capacity by helping land owners protect the soil, water, forests, and other natural resources. The Department, through inspection and grading services, safeguards and assures standards of quality in the daily food supply.[14]

To accomplish these goals, USDA conducts many R&D projects. It operates the Agricultural Research Service, which provides the knowledge and technology for improved farm operation and conservation of the environment. Research is conducted in cooperation with individual states, other federal agencies, industry, universities, and other research organizations.

The Department also operates the Cooperative State Research Service which administers grants for research. These funds generally go to state-operated Agricultural Experimentation Stations and other state institutions. The Department promotes probably the world's largest organization dedicated to the transfer of technology: the Agricultural Extension Service. This Service is the educational agency of the Department. Its purpose is to convey to current and potential users the latest technology developed through research by the land grant universities and other Department-supported research.

Of significance, the fiscal year 1978 USDA budget request, if approved, will permit USDA to support basic research through grants to universities and other institutions.

The Department of Commerce (DOC) directly promotes the nation's economic development and technological advance and encourages the competitive free enterprise system through a wide variety of programs. It offers advice and information to domestic and international business; provides social and economic statistics and analyses for business and government planners; assists in the development and maintenance of the U.S. Merchant Marine; provides research for and promotes the increased use of science and technology in the development of the earth's physical environment and oceanic life; promotes travel to the United States by residents of foreign countries; assists in the growth of minority businesses; and seeks to prevent the loss of life and property from fire.[15]

Among its science-related activities, the Department operates the National Bureau of Standards (NBS), which has a dual responsibility: to be "a central reference laboratory for all kinds of measurements in engineering, physics, and chemistry" and "to apply this basic competence to solve problems." The Bureau recently has been reorganized, and performs these duties through the newly-created National Measurement Laboratory and National Engineering Laboratory, and the Institute for Computer Sciences and Technology, which has been carried over from the old organizational structure.[16]

The National Science Foundation (NSF) is the key federal agency promoting the progress of science. Its support is made through grants, contracts, and cooperative agreements awarded to universities, and nonprofit and other research organizations. It selects projects in response to proposals from scientists. These proposals are evaluated through a procedure based on peer review. NSF emphasizes basic research, the search for improved understanding of the fundamental laws of nature through all scientific disciplines. Its educational programs promote increased understanding of science at all educational levels and encourage an adequate supply of scientists and engineers to meet U.S. needs.[17] It is also involved to a modest degree in applied research.

NSF encourages cooperation among universities, industry, and government. It supports major national and international scientific investigations, such as the U.S. Antarctic Research Program, and provides funding for the exchange of American and foreign scientists and engineers. NSF contracts also make the facilities of national centers available to qualified scientists. These include observatories and the National Center for Atmospheric Research.

NSF also plays an active role in national science policy planning. It funds research aimed at formulating science policy and develops and disseminates information about scientific resources, particularly scientific and engineering manpower in relation to future needs.

Other federal agencies which support relatively extensive science-related activities include:

Department of Housing and Urban
   Development
Department of Interior
Department of Transportation
Environmental Protection Agency
Veterans Administration

Private Scientific Advisory Bodies

Four private scientific advisory bodies deserve mention as we conclude our discussion. The National Academy of Sciences (NAS) is an organization of distinguished scientists and engineers dedicated to the advancement of science and its use for the general welfare. Although not a governmental agency, the Academy has long enjoyed close relations with the administration. Its charter of 1863 specifies that "... the Academy shall, whenever called upon by any department of the government, investigate, examine, experiment, and report upon any subject of science or art, the actual expense of such investigations, examinations, experiments, and reports to be paid from appropriations which may be made for that purpose, but the Academy shall receive no compensation whatever for any service to the Government of the United States." Thus, no federal funds are appropriated directly to the Academy, the principal funding mechanism typically being the negotiation of contracts with government agencies.

Grants and contracts with the federal government account for approximately 70 percent of the Academy's work, with the remainder divided between work for non-governmental institutions and general administration. Table 3-3 shows the distribution of the Academy's income from U.S. government agencies in fiscal year 1976-1977. As the table indicates, the Academy is involved in problem solving across the entire government spectrum. A large percentage of the total expenses of NAS in 1976-1977 ($44,828,826 of $55,642,500) was allocated to government and private advisory and research activities. Even though much of its funding comes from the federal government, the Academy is an independent institution, and its license to speak out freely on problems of public policy is assured.

Second, the National Academy of Engineering (NAE) shares in the objectives and responsibilities of the NAS by drawing on eminent engineers to sponsor engineering programs aimed at meeting national needs, encouraging engineering research, and advising the federal government upon request in matters of engineering.

Third, the National Research Council (NRC), which was organized by the NAS to facilitate the participation of a broader representation of scientists and technologists in carrying out its objectives, serves as the principal operating agency of NAS and NAE. The purpose of the Council is to stimulate scientific research and to foster the application of research findings to engineering, agriculture, medicine, and other useful arts.

Fourth, the Institute of Medicine, one of the NIH, was established in recognition of the important and complex problems posed in the provision of adequate health services to all sectors of society. The Institute identifies, for study and analysis, important issues and problems that relate to health and medicine;

TABLE 2-3

FEDERAL SOURCES OF FUNDS FOR THE NATIONAL ACADEMY OF SCIENCES

Department of Agriculture	$ 136,778
Department of Commerce	1,403,906
Department of Defense	
Department of the Air Force	847,667
Department of the Army	1,256,493
Department of the Navy	2,567,093
Department of Health, Education, and Welfare	3,630,197
Department of Housing and Urban Development	335,266
Department of the Interior	665,478
Department of Justice	276,230
Department of Labor	214,176
Department of State	282,646
Department of Transportation	5,136,298
Executive Office of the President	6,589
Agency for International Development	1,221,189
Energy Research and Development Administration	10,118,428
Environmental Protection Agency	3,013,550
Federal Aviation Agency	57,628
Federal Energy Administration	31,206
General Services Administration	66,320
National Aeronautics and Space Administration	5,559,948
National Foundation on Arts and Humanities	1,973
National Science Foundation	7,957,012
U.S. Senate	5,180
Veterans Administration	1,008,544
Prior years' adjustments, various agencies	(1,489)
Total	$45,798,306

Source: NAS Annual Report for F.Y. 1976-77. Total income was $55,157,858.

initiates and conducts studies of national policy and planning for health care and health-related education and research; responds to requests from the federal government and other agencies for studies and advice on matters relating to health and medicine; establishes liaison with the major scientific and professional societies in the field; and disseminates information to the public and the relevant professions.[18]

The Legislative Branch

Congress is less directly involved in science policy than the Executive Branch, but its role is still important. Under our system of checks and balances, it must counterbalance the authority and influence of the Executive Branch and initiates major action it believes the administration has neglected. Its control is exercised partly through discussion of proposals or bills originating with the administration and partly through examination of the President's annual budget.

Individual Congressmen have been influential as sponsors of R&D in government departments they oversee. The rapid growth in expenditures in health research, for example, can be largely attributed to the personal interest taken by a number of powerful Congressmen in the 30 years following World War II. Each Congressman, moreover, has a staff to assist him; recently, many staff members have become knowledgeable about R&D (although few have technical training). They are usually more accessible than the Congressmen they serve and are often influential in preparing legislation that affects research programs. Congressional hearings, which are almost always held before new legislation is voted on, serve to bring out conflicting views on the influence government activity may have on science and technology.

Recently, Congress has been taking more independent actions to affect the country's R&D rather than simply affirming or rejecting proposals from the Executive Branch. In 1970, for example, it amended the Appropriations Act of DOD to stipulate that no authorized funds could be used unless the research project had direct and appropriate relationship to a specific military function. This so-called "Mansfield Amendment", legislated in apparent disregard of the wishes of the President and certainly against the better judgment of the technical community, has cut down drastically on basic and exploratory research by DOD contractors and has been harmful to some small companies who relied on such support for much of their research.

Congress is also an important--perhaps the most important--medium through which public opinion related to technological issues is communicated to the government. Public opinion has been effectively expressed on such issues as food additives, environmental protection, and solar energy.

Carrying out such wide-ranging duties requires specialized bodies. Congress has distributed its operations and responsibilities to various committees: 15 standing committees in the Senate, 22 in the House, and 32 joint committees (Table 3-2). The most important committees for planning scientific and technical R&D and three Congressional agencies are described briefly. There is no one committee with sole responsibility for science policy.

Committees of the House of Representatives

The Committees of the House of Representatives are shown in Table 3-2.

The Agricultural Committee, whose competence extends to all the activities of the USDA, deals with questions of agricultural education, research, and experiments.[19]

The Appropriations Committee is responsible for studying and discussing the budget proposals presented by the President and then submitting the final text for House approval. So much work is involved that the Committee has split up the various duties among subcommittees having precise but extremely wide competence. Their influence is considerable and their conclusions are not usually discussed by the plenary committee; the budget is voted by the House or the Senate clause by clause, without general debate, and the proposals of the Appropriations Committee are not often challenged.[20]

The Appropriations Sub-Committees thus analyze closely each year the administration's financial proposals at hearings The sub-committees tend to reduce the appropriations requested by the administration. Science and technology programs may be easy victims for these cuts because of the approximations and uncertainties of estimates for R&D expenditure. Scientific affairs are not subject to overall presentation as a science budget. Responsibility for their budgetary analysis is divided among the various sub-committees.[21]

The Armed Services Committee is responsible for keeping watch on all DOD activities, including the Army, Navy, and Air Force R&D programs.[22]

The Education and Labor Committee is particularly concerned with analyzing the impact of technological changes on manpower.[23]

The Government Operations Committee, which assesses the organization of the executive agencies, has set up a Sub-Committee on Research and Technical Programs to consider mainly the scientific and technical enterprise of the federal government.[24]

The Committee for Interstate and Foreign Commerce is particularly interested in problems of transportation, communications, power, meteorology, and health.[25]

The Merchant Marine and Fisheries Committee supervises the Coast and Geodetic Survey and considers shipping, oceanography, and the protection of wild life.[26]

The Science and Technology Committee is concerned with domestic and international scientific planning, analysis, and cooperation, and research in space science, fossil and nuclear energy, transportation, the weather--in general, in all scientific and technical research.

Committees of the Senate

The Committees of the Senate and Joint House and Senate Committees are shown in Table 3-2. The scope of most of the main Senate committees is similar to that of their counterparts in the House of Representatives. The more important committees concerned with science and technology are:

Agriculture, Nutrition, and Forestry
Appropriations
Armed Services
Budget
Commerce, Science, and Transportation
Energy and Natural Resources
Environment and Public Works

Congressional Agencies

A significant resource for Congress is the Congressional Research Service (CRS) of the Library of Congress. CRS provides information and analyses to members of Congress on scientific and technical matters. The Science Policy Division of CRS alone employs about 45 professionals who respond to requests for technical information and perform technical studies for Congressional offices and committees. Other CRS divisions, such as Energy and Environment, also supply committee staffs and members of Congress with information on technical subjects. According to a recent study, CRS is currently "in transition from being an organization preoccupied with legislative reference services to becoming a policy analysis and research arm of the Congress."[27]

Anouther source of studies and policy recommendations for Congress is the Government Accounting Office (GAO). Particularly in the area of appropriations and allocation of funds, GAO, which is a Congressional agency, shapes Congressional programs. According to the Legislative Reorganization Act of 1970, the

Comptroller General of the United States, as the head of GAO, has the authority to "review and analyze results of government programs carried on under existing law, including the making of cost-benefit studies." Title VII of the Congressional Budget and Impoundment Control Act (1974) established an Office of Program Review and Evaluation within GAO. Additionally, the Science and Technology Sub-division of the Procurement and Systems Acquisition Division supplies technical surveys and reports to Congress.

Thus, both GAO and CRS do important research for Congressional committees, even to the extent of making policy recommendations. Their services are supplemented by Congressional Science and Technology Fellows, who are funded by such scientific societies as the American Association for the Advancement of Science, the American Physical Society, the Institute of Electrical and Electronic Engineers, and the American Institute of Aeronautics and Astronautics, for one-year appointments to examine legislative problems in science and technology.[28]

The Office of Technology Assessment (OTA) also helps Congress anticipate and plan for the consequences of technology. The Office provides an independent source of information about the impacts, both beneficial and adverse, of technological applications, and identifies policy alternatives for technology-related issues.[29] One important reason for establishing OTA was Congress' sense that its access to advice on technological problems and their solutions was not as direct as that of the Executive Branch.

The Technology Assessment Act specifies that OTA consist of a Technology Assessment Board, a Director and Deputy Director, a Technology Assessment Advisory Council, and such other employees and consultants as may be necessary. The Congressional Board sets the policies of the Office and is the sole and exclusive oversight body governing OTA. The Director, who is appointed by the Board for a six-year term, is the chief executive officer. He is responsible solely to the Board, of which he is a member.

OTA provides Congressional committees with studies that identify the broad range of consequences, social as well as physical, expected to accompany various policy choices affecting the uses of technologies. More specifically, the functions of OTA are to:

1. Identify existing or probable impacts of technology or technological programs, and, where possible, ascertain cause-and-effect relationships
2. Identify alternative programs for achieving requisite goals
3. Estimate and compare the impacts of alternative methods and programs
4. Present findings of completed analyses to the appropriate legislative authorities
5. Identify areas where additional research or data collection is required to provide support for assessment
6. Undertake such additional associated activities as may be directed
7. Assist the Congressional Budget Office on science and technology programs.

In carrying out the provisions of the Technology Assessment Act, the Office cannot operate laboratories, pilot plants, or test facilities. It is authorized to secure directly from any executive department or agency information, suggestions, estimates, statistics, and technical assistance to carry out its functions. According to statute, if certain expertise is required, OTA may request, and the head of any executive department or agency may detail, with or without reimbursement, any of its personnel to assist the Office.[30]

The Technology Assessment Board has established several broad program areas including energy, food, health, materials, oceans, transportation, communications, space technology, genetics, national security, and international technology affairs.[31]

Requests for OTA assessments may be initiated by:

1. The chairman of any standing, special, select, or joint committee of Congress, acting for himself or at the request of the ranking minority member of a majority of the committee members
2. The OTA Board
3. The OTA Director, in consultation with the Board.

In arriving at decisions, the Board considers recommendations and plans developed by OTA staff and applies the following general selection criteria, developed in consultation with the Advisory Council:

1. Is this now or likely to become a major national issue?
2. Can OTA make a unique contribution, or could the requested technology assessment be done effectively by the requesting committee?
3. How significant are the costs and benefits to society of the various policy options involved and how will they be distributed among various impacted groups?
4. Is the technological impact irreversible?
5. How imminent is the impact?
6. Is there sufficient knowledge available to assess the technology and its consequences?
7. Is the assessment of manageable scope? Can it be bounded within reasonable limits?

8. What will be the cost of the assessment?

9. How much time will be required to do the assessment?

10. What is the likelihood of Congressional action in response to the assessment?

11. Would this assessment complement or aid other OTA projects?[32]

Intra-Government Coordination

Because of this highly decentralized organization of the federal government, several organizational structures, both formal and informal, have been developed to coordinate and manage R&D across department and agency lines.

Preeminent in the formal group is FCCSET, which seeks to identify areas for interagency coordination and establishes permanent or ad hoc committees as necessary. Ad hoc interagency committees or a joint administration may be employed to monitor R&D programs falling within the missions of two or more departments or agencies, each having roughly equal responsibility and each contributing a portion of the cost. A joint program office is often used to direct R&D efforts aimed primarily at contract research with the private sector. The Joint Office of Noise Abatement is one example. Yet another form of formal coordination is a multi-agency committee to direct several groups researching a single field. The Inter-Agency Committee on Oceanography (ICO), functioning since 1959, is one of the most sophisticated, and perhaps the most effective, example of interagency coordination in the U.S.[33]

If the scale and urgency warrant, the government is likely to create a new single-purpose agency as a center for R&D. Examples can be cited. The National Oceanographic and Atmospheric Administration was created in DOC through reorganization and integration of previously scattered elements of the bureaucracy concerned with meteorological science, weather forecasting, atmospheric research. NASA was established to concentrate funds, managerial skills, scientific and technical talent, and special authorities in an organization to undertake a crash program of unprecedented proportions. The EPA, in a similar way, came into being as a focus of regulatory and R&D activities under the National Environmental Policy Act. To some degree, these actions tend to abridge the strong tradition of decentralization of R&D within government; they help illustrate the organizational implications of the systems approach to problem solving.[34] But the tendency to set up specialized R&D agencies to overcome ingrown traditions and practices of the user agencies is matched by a conflicting tendency to believe that the agency responsible for using the results of the research is best suited for defining and creating the technology it needs.[35]

An informal level of coordination exists among the program directors at federal agencies that support R&D. Several groups of program directors meet on a formal basis under the sanction of FCCSET. Other groups, such as the chemistry group called the Federal Interagency Chemistry Representatives (FICR), meet on an informal basis about twice a year.[36]

Scientists and agencies engaged in basic research under U.S. government funding are usually coordinated differently from those in applied research. Basic scientists are more independent; individual investigators keep abreast of their fields and bring their research findings to the attention of their colleagues. In applied research, the funding agency provides guidelines for problems to be addressed and follows the progress of the research to apply the results. However, much reliance is still placed on the investigators' coordinating in their own way with colleagues.[37]

In government-supported development, as distinct from research, a strong government role in coordination is a well accepted practice. Considerable reliance is placed on interagency mechanisms. Many development projects are unique to the sponsoring agency's mission and coordination is consequently directed to integrating the project with related effort in-house or elsewhere.[38] Placing too much reliance on cooperation of the individual scientists within the scientific community itself for the coordination of research causes occasional problems, however. The need for expensive facilities and equipment in some scientific areas requires close coordination.[39]

The Roles of the Federal Government in Applied Research and Technological Innovation

No article of the Constitution or single major piece of legislation spells out the conditions under which the federal government should concern itself with science and technology or with their application to national needs. Instead a very general set of guiding principles has evolved. These have broad acceptance in American society as a whole although there may be controversy--sometimes bitter and divisive--on the application of these principles to specific problems.

In its influence on technology, the government can be characterized by two broad objectives:

1. Creation of the technological base essential for the agencies of the government to perform their functions effectively
2. Stimulation of those technologies that benefit society as a whole, where private sector forces are inadequate to cause the technology to be developed.[40]

The bulk of government spending for technology responds to the first objective. This includes programs for national defense, for the protection of public health, for the support of public facilities, and for a variety of other activities falling within the federal sector. Technologies related to specific objectives of government agencies also benefit society as a whole through their adoption for private sector use. Recognizing this two-fold benefit, R&D performing agencies have specific programs devoted to enhancing the transfer of their technology into the private sector.[41]

A smaller but growing government effort is aimed at the second objective, at technology of benefit to society, but for which private sector incentives are insufficient to justify its creation. The government intervenes when external economies and uncertainties inhibit private investment in technology or when the scale exceeds the capabilities of the private sector. To compensate for inadequate private investment, government can act either indirectly by increasing private incentives and capabilities, or directly by developing the technology for private sector use (Figure 3-1).[42]

It would not be feasible to discuss here the specific guidelines for federal participation. It is interesting to consider how certain general principles have shaped a set of criteria for government involvement.

1. The size of the effort or the length of time to accomplish it is greater than most private firms can manage. This is particularly true for industries which are made up of small companies (as the coal industry was).

2. The benefits of the research cannot be recaptured by private institutions even though they may be important to the country.

3. The risks of a project are too great for any single company to assume.

4. The research is primarily for military purposes.

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5. The research is directed to discovering new laws of nature (basic research).

6. The research will stimulate competition in concentrated industries.

7. The research will assist industries that are under current economic stress.

8. The research is on problems whose solutions require the rapid development of new technology because of the enactment of new laws and regulations.[43]

In addition to these criteria, a balanced government R&D program displays the following general characteristics:

1. Provides reliable support of basic research

2. Helps to provide an adequate educational base for the needed scientific and engineering manpower

3. Utilizes where possible the results developed in other government and industry R&D programs

4. Stimulates the transfer of research results into commercial programs.

In the Non-Nuclear Research and Development Act of 1974, Congress was somewhat more specific in establishing criteria for federal involvement in non-nuclear energy R&D:

1. The urgency of the public need for potential results is high and it is unlikely that such results would be achieved in a reasonable time without federal assistance.

2. The potential opportunities for non-federal interests to recapture the investment in the R&D through normal commercial use of proprietary technology appear inadequate

3. There are limited opportunities to induce non-federal support of the undertaking by offering new incentives

4. The degree of risk of loss of investment in the research is high

5. The magnitude of the investment appears to exceed the financial capabilities of potential non-federal participants.[44]

The Budgeting Process for Federal R&D

Even when the government decides on a research program, it is still presently impossible to determine the best level of resource allocation. There seems to be no level which professionals agree is the right volume of research. Decisions are based on many criteria: the trend of public opinion, the attitude of Congress, the line followed by various public and private institutions. A new and frequent criterion is: how much is society prepared to pay? And so we find, in medical research, for example, that regular annual increases in budget appropriations have been made without any consistent justification.[45]

The initiative for scientific and technical R&D may arise from the President and his staff, from a federal agency or department with responsibility for the area in which a problem lies, from Congress, from private individuals, from special interest groups that stand to gain by government funding of solutions, and from a perceived desire of the general public--perceived either by Congress or the Executive Branch. Independently of how recognition of a problem comes about, the problem is not accepted as a federal responsibility until a budget is approved that appropriates money for its solution. A budget proposal may be initiated in one of two ways. The President may include it in his budget request, or Congress can initiate separate legislation appropriating funds.[46]

More specifically, the United States, as we have seen, has what we cann an "executive" budget. The President proposes the budget, but Congress has the sole power, under the Constitution, to appropriate money. There is no special budget, and no special budget process for R&D. The executive budget is prepared on a departmental basis, with each department submitting estimates of its needs to the President's budget staff (Table 3-1). The departmental estimates are prepared under guidelines and constraints laid down by the President. They blend demands and proposals from each bureau of a department with the Department Head as the arbiter and referee. R&D is justified as an element within a bureau's mission. The final budget is resolved by the President's budget staff on the basis of fiscal policy, Presidential priorities, program objectives, and bargaining. Congress then decides to approve, increase, or reduce the executive budget. Attempts are made to inject scientific and technical advice during the executive budget process. Efforts are also made to ensure coordination and balance in the R&D programs and to ask questions about productivity, costs, and managerial efficiency. But the final outcomes are largely the products of decisions on agency requests, rather than the application of resources to an integrated set of R&D objectives. Crosscutting R&D reviews are made, however, in selected and aggregated categories (Table 3-4).[47]

Each federal agency prepares an R&D plan and budget to support its mission. Again it should be emphasized that this is not a separate item which is considered in isolation but rather part of the total plan of the agency to be reviewed in the total context. While it is possible to aggregate all of the R&D plans and budgets of the individual agencies and arrive at a total planned level of budgeted expenditure, it would be a mistake to assume that this is a centrally derived figure which represents the prior top down judgment of how much total R&D the federal government should support. Rather, such a figure is simply the aggregate of the Presidentially-approved plans of the many agencies, each pursuing its own mission--a portion of which requires R&D.[48]

The budgeting process itself makes R&D planning difficult. Budget requests for R&D in the federal sector arise in many different mission-oriented agencies, each arguing that its mission has the highest funding priorities. The budgets are always prepared by advocates of a given research program and generally propose a large number of parallel efforts to be conducted simultaneously. Final budget levels are generally set considerably lower by agency budget reviewers than what has been requested. The reasons for such budget cuts include lack of good justifications, unconvincing cost estimates, various state-of-the-art considerations, duplication or lack of affinity with the agency's mission, and budget constraints. In some cases such cost reductions occur because under Zero Based Budgeting all proposed projects have been ranked by the sponsoring agency and those at the bottom of the list must be eliminated to balance budget requests with funds available.

Each individual agency budget submission for its total mission, including R&D, is reviewed by OMB, one segment of which is responsible for reviewing the R&D portion of agency submissions. These reviews are strongly influenced by the President's overall budget limits. Competing claims for resources come under scrutiny in this process of aggregation and the Science Advisor's staff works with OMB in sorting out the issues and recommending means of resolution. After the total federal budget is submitted to Congress, the programs and budgets are reviewed by the appropriate committee in both the Senate and the House. No committee is charged with reviewing just the R&D portion of all agency budget proposals.[49] During the Congressional process public interest groups voice their opinions as to the adequacy or wisdom of any of the programs.[50]

The procedure for selection of R&D programs is thus as complex as the scores of steps of the prolonged

TABLE 2-4

SUMMARY OF THE "SPECIAL ANALYSIS OF FEDERAL RESEARCH AND DEVELOPMENT PROGRAMS" PREPARED BY THE OFFICE OF MANAGEMENT AND BUDGET

(obligations in millions)

	FY 1975 Actual	FY 1976 Estimated	FY 1977 Budget	Percent Change
Total Conduct of R&D	$19,023	$21,636*	$23,465	+8.5%*
Total R&D Facilities	821	909	1,215	+33.7%
TOTAL R&D	$19,844	$22,545*	$24,680	+9.5%*
Conduct of R&D				
Defense-Military Functions	$ 8,987	$ 9,879	$11,198	+13.4%
NASA	3,088	3,473	3,573	+2.8%
ERDA	2,071	2,812	3,282	+16.7%
HEW	2,395	2,667*	2,570	-3.6%*
NSF	604	628	726	+15.2%
Agriculture	424	483	507	+5.0%
Transportation	291	340	319	-6.2%
Interior	296	332	316	-4.8%

TABLE 2-4 (Continued)

EPA	$ 258	$ 305	$ 241	-21.0%
Commerce	222	247	243	-1.6%
Veterans	99	108	106	-1.9%
Nuclear Regulatory Commission	61	97	109	+12.4%
HUD	57	62	70	+12.9%
Justice	44	65	41	-36.9%
Smithsonian	25	27	33	+21.0%
Labor	24	29	32	+11.7%
AID	21	25	32	+28.1%
TVA	17	20	22	+12.2%
Corps of Engineers	12	12	13	+2.5%
Civil Service Commission	4	4	7	+65.0%
FEA	1	4	6	+60.5%
Consumer Product Safety Commission	5	2	4	+79.2%
Library of Congress	3	3	4	+20.0%
Treasury	3	3	2	-7.7%
ACDA	1	2	2	+43.8%
State	2	2	2	
FCC	1	2	2	-20.0%
FTC	1	1	1	+7.7%
GSA	6	2	1	-37.5%
CAB	**	**	1	+25.0%
Office of Telecommunications Policy	1	1	1	-37.5%

TABLE 2-4 (Continued)

TOTAL, Conduct of R&D	$19,023	$21,636*	$23,465	+8.5%*
R&D Facilities				
ERDA	$ 393	$ 461	$ 638	+38.4%
Defense-Military Functions	164	176	356	+102.2%
NASA	143	82	124	+54.9%
NSF	31	52	34	+34.6%
HEW	39	27	11	-59.3%
Transportation	13	20	16	+20.0%
Agriculture	8	36	3	-91.7%
Commerce	10	8	6	-25.0%
EPA	2	7	4	-42.9%
Interior	6	1	1	-30.0%
Veterans	2	14	6	-57.1%
Nuclear Regulatory Commission	2	10	8	-20.0%
Consumer Product Safety Commission	2			
Smithsonian	**	1	**	-50.0%
TVA	12	15	9	-44.2%
OMB Discrepancy	-6			
TOTAL, R&D Facilities	$ 831	$ 909	$ 1,215	+33.7%

TABLE 2-4 (Continued)

TOTAL R&D	$19,844	$22,545*	$24,680	+9.5%

NOTE: Detail may not add to total because of rounding

* Amount in "Special Analysis P" increased by $298 million for estimated effect of Congressional override of President's veto of Labor-HEW appropriation bill

** Less than $0.5 million

budgetary preparation, approval, and implementation process of the federal government because of the decentralized nature of the R&D planning process. A "Special Analysis of Federal Research and Development Programs" is prepared each year by OMB (Table 3-4). But R&D budgets are simple indicators of level of effort; they tell nothing about need, quality, or output.[51]

Thus, no unified R&D budget is presented and justified to Congress. There is, in fact, some fear that such a presentation might cause those unfamiliar with the uncertainties of research to insist on a degree of prioritization in R&D programs which would be impractical and unhealthy.[52]

The Government as Performer of Research

Although only 26 percent of the R&D funded by the federal government is carried out in its own laboratories, the importance of such in-house research should not be minimized. Certain laboratories have a tradition of scientific and technical excellence built up for many decades, and a number of their individual researchers and research groups have attained national and international stature. One significant example is the Naval Research Laboratories whose fundamental work on surface chemistry and lubrication is widely acclaimed. NBS in DOC has long been the nation's center for precise determination of physical properties and improvement in the process of measurement, issuing a stream of standard reference materials. NBS works in fields as diverse as microcalorimetry, lasers, heat transfer, and flame proofing of fabrics.[53] The former Bureau of Mines became years ago a world leader in studies of the fundamental properties of hydrocarbons, explosion phenomena, mine safety technology, and coal use.

Agricultural research has had a long and productive history. USDA has its own laboratories and field testing stations which study production and quality of field crops and uses of agricultural products. Since the 1930s the Tennessee Valley Authority has also developed and tested new fertilizers. In large measure the success of the government's agricultural research results from its well-integrated program for disseminating the results of its work, a network of land-grant colleges and experiment stations (see page 88). NIH, EPA, and DOE also maintain mission-oriented laboratories which work on both specific projects and long range assignments.

Financial arrangements for these government-sponsored laboratories differ from one agency to another. Typically, the director of the institute has only modest flexibility to rearrange funds and projects. As an example, the budget for a DOE-supported institute like the Brookhaven National Laboratory, is divided into funds for support facilities, capital funds for new construction, and funds for support of R&D activities. The R&D funds themselves are subdivided into categories: one supports the operation and experiments at the proton accelerator; another supports the chemistry research activities, etc.[54]

No common body administers the government's laboratories. Instead, these R&D facilities are operated by the various agencies and departments to whose general purposes they directly relate. Some inter-agency and inter-laboratory contracting takes place, but this constitutes only a small portion of the work. Government laboratories perform R&D for industry only under special circumstances.

Federally Funded Research and Development Centers (FFRDCs). These R&D performing organizations are exclusively or substantially financed by the federal government to achieve a specific R&D purpose. Eight are administered by companies and 22 by universities or consortia of the universities (Table 3-5). Those affiliated with universities also provide facilities for training and for general support of related research elsewhere in the university. Although they perform R&D work on direct request, or under a broad charter, from the sponsoring federal agencies, the university-affiliated FFRDCs are organizationally

TABLE 2-5

R&D EXPENDITURES AT FFRDC'S BY FIELD: FY 1975*

TOTAL	$987 million
Physical Sciences	54%
Engineering	28%
Mathematical and Computer Sciences	6%
Environmental Sciences	6%
Life Sciences	4%
Other Sciences	2%

* Federally Funded Research and Development Centers administered by universities

Source: National Science Foundation

separate from the administering institutions. The freedom of movement of graduate students and faculty between the university and FFRDCs which it administers has undoubtedly had mutual benefit.

The 22 university-affiliated FFRDCs spent in 1975 about a billion dollars, approximately equally divided among basic research, applied research, and development.[55] The eight FFRDCs administered by private firms spent about three-quarters of a billion dollars, of which in turn three-quarters was spent on development. The Atomic Energy Commission, now part of DOE, sponsored all the company-affiliated FFRDCs and 10 at universities.[56] Other university FFRDCs were funded by DOD, NASA, and NSF.

Non-For-Profit Corporations. The federal government also utilizes a number of not-for-profit corporations which assist it as quasi-official organizations. They result from the scientific and technical complexity of government operations (especially in activities such as defense and space exploration) and the need to provide support for these operations. The object is to draw together an expert staff unhindered by the strict Civil Service rules and to combine the best features of research in industry and the university. Some of these corporations are the direct consequence of administrative initiative; others have evolved from their original role of contractor to federal agencies. At present two major categories can be distinguished: the specialized bodies and the "think factories".[57]

The specialized bodies have two very different roles. Some of them are organizations for the technical administration of major projects (e.g., ballistic weapons) whose implementation is dispersed among a considerable number of industrial, university, or national estabilsyments. Insulated from market pressures and the daily grind of administrative activity, organizations such as the Aerospace Corporation ensure the technical control and coordination of programs. In this capacity they are particularly suitable for crash programs. Their prerogatives are, however, tending to be reduced with increasing technical competence in the administration, which has sometimes experienced difficulty in keeping such outside organizations unders it own authority. Others are organizations carrying out special missions for the administration (and sometimes for industry) because of their special skill. The best known example is the Systems Development Corporation (SDC) for computer technology. Private industry regards with great disfavor the activity of these organizations which are accorded substantial advantages in competing for government contracts.[58]

The "think factories" are in fact consultative bodies which made their appearance at the end of World War II. Their highly skilled personnel have worked out both elaborate methods to analyze the political or other policy alternatives of the moment and techniques of administrative management. They, too, are independent institutions with legal autonomy, registered in the state where they are established as non-trading corporations. The best known of these establishments is the Rand Corporation, created on the iniative of the Air Force. At present, the Corporation contracts essentially with the Air Force, DOD, and NASA.[59]

The Government as Funder for Research

Although the government does perform some of its own R&D, a more common practice is for the government to assign to private industry and the universities the major role in performing research (Tables 3-2 and 3-3). As we have seen, the government provides 53 percent of the funding for all R&D carried out in the U.S. It is particularly significant in the funding of basic research; the government finances an estimated 68 percent of all basic research done in the country. Different mechanisms have been developed to plan and manage the government's financing of both basic and applied research. These mechanisms are discussed in the following sections.

Basic Research. Government support is vital to the health, even the existence, of basic research. Most basic research in industry, while contributing to scientific knowledge, is still limited by the profit needs of the corporation. But planning and budgeting for basic research is a baffling problem. Few useful objective criteria present themselves. The government tends to rely on the judgments of experts, especially their perception of scientific areas showing exciting progress. Results from other countries also can stimulate increased support in a particular field. Maintaining a flow of Ph.D.s and providing necessary support to the research universities are also desirable. Since even the most basic research cannot be treated as if it were entirely divorced from the needs of society, government policy must incorporate long-range forecasts of the role of new scientific knowledge in forging technology which will improve the welfare of the American people.[60]

Although mission agencies fund basic research, NSF has become the preeminent supporter of such programs in universities, providing about half of what the government spends for what is termed "the science and technology base". Almost all the agencies rely to a great extent on selected panels of experts for recommending the choice and level of funding for fundamental research projects eligible for support. NSF, however, has refined to a high degree the process of peer review in which experts in the field in question anonymously review and appraise proposals. Although this system has been attacked as unduly favoring the well-recognized investigators and the well-established institutions, such criticism has generally been disputed. No alternative method seems both equitable and feasible.

NSF and other agencies such as the NIH rely heavily on the grant mechanism for funding research in universities. Grants differ from contracts (see next section) in that the federal government has always considered that grants were not intended to buy the result of research but to establish an association between the government and the universities or other grant receivers. The arrangements for this association vary with the agencies and universities concerned.[61] But the following criteria are typical.

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1. The costs most commonly shared between educational establishments and the agencies are the salaries of teaching staff engaged on a federal research program. Some universities prefer to preserve their financial autonomy by bearing the whole of these costs, but few are rich enough to do so.

2. Costs must be divided when the agency agrees to bear only part of proposed research expenditure ("matching grant"); this technique is intended to encourage the universities to develop their own research programs and is used particularly for financing equipment and the various systems of institutional grants.

3. The university may decide to use its own resources to continue a research project for which federal funds have been discontinued.[62]

The federal reimbursement of indirect costs incurred by an institute of higher education while performing research for the federal government was, until recently, limited to 20 percent of the direct program costs. This ceiling was too low for many universities.[63] More flexible legislation now allows the agencies and institutes concerned to negotiate an ad hoc division of costs in each case.[64]

Although the bulk of federal support for academic research is still earmarked to individual projects, the grant system is being diversified, for various reasons:

1. The desire to simplify federal action concerning academic research to ensure better program coordination

2. Congressional pressure, frequently exerted in favor of closer control over the use of

resources assigned to academic research

3. The desire of university authorities to safeguard their overall responsibilities, which may be affected by the fragmentation inherent in the project system

4. The desire to associate science policy with a higher education policy designed to improve the quality of the country's education and research

5. The determination to ensure a better geographical and institutional distribution of credits

6. The requirement in many research projects of a big staff and large-scale equipment.[65]

A grant can be used to sponsor any research at universities or colleges. It differs from a contract in that the funds for the work are advanced to the performing group at the time of award. In a typical contract, in contrast, the funds are provided by the sponsor as the contractual work proceeds or at the end of the contract on receipt of the final report. Usually a grant permits the performing group to retain rights to equipment purchased for performance of work, whereas in a contract, equipment and non-expendable supplies are the property of the sponsor.

In addition, at times the government is able to afford institutional development grants to improve the capabilities and competitiveness of institutes which are not of the first rank. The aim is to increase the number of centers of scientific excellence and thus overcome the problem of distributing the bulk of funds to a relatively few institutions.

Funds are also distributed partly to continue existing research teams and long-term research programs. Because R&D funds must be obtained from Congress each year in the budget process, increments of support rather than guaranteed funding must be provided.

With such principal funding agencies as the NIH or the National Institutes of Education, a high percentage of each year's new money must be set aside for continuation of existing grants. This creates some difficulties in supporting promising young research scientists and desirable new starts in research.[66]

Assistance Relationships and Cooperative Agreements. A recent law, the Federal Grant and Cooperative Agreement Act of 1977, provides for a type of government assistance intermediate between a grant and a contract. In a grant there is minimal involvement by the government in the conduct of the research. In a contract, the government spells out in considerable detail the R&D it is procuring and monitors the effort.

A third type of relationship is envisioned: an assistance relationship in which the government agency is significantly involved in the research. In such a "cooperative agreement" there will be much flexibility in negotiating the division of work, cost sharing, and patent rights.

Profit-making organizations, which have been largely excluded from the grant wystem, are eligible for this type of assistance award; but it is too soon to tell whether private industry will actively compete for them.

Applied Research. The situation understandably is different for government support of applied R&D. Here the government agencies are seeking results in the form of specific technical information--and on occasion prototypes of a novel product--which will aid in accomplishing their own missions, often in the short-term. Techniques of management and evaluation differ.

Contract R&D is one of the principal mechanisms for funding R&D in the United States. Over 40 percent of the total R&D performed in the United States is performed under contract, the major part of the funding, of course, coming from the federal government. Applied R&D is usually funded by cost and cost-plus-fixed-fee agreement. Cost sharing is sometimes used, but mostly in large-scale development projects in which the government is funding an industry performer. A joint R&D contract may be attractive in carrying out research sponsored by industry organizations. Fixed-price contracts are rarer because of the inherent uncertainties of R&D.

An understanding of the types and ranges of application of R&D contracts requires an appreciation of the basic purpose of contractual R&D and of the circumstances under which it can be most effective in relation to the total R&D effort.

As in other areas, our technological society has developed specialization in R&D skills. Because of the interdisciplinary nature of technological progress, even large, multi-disciplined research staffs, wheter in government, industry, or the academic community, frequently require highly specialized skills and facilities not available internally. Rather than employ people with these skills and invest in the physical plant necessary to conduct the research, it is more judicious to contract with an organization that has these skills and facilities. Savings in time and capital to the organization sponsoring the particular program are frequently achieved. However, such subcontracting of research is subject to certain constraints. The contractual format reflects these constraints and depends on the research approach of the performing organization as well as the flexibility of the contracting groups in negotiating a mutually satisfactory agreement.

The following sections detail the mechanisms and administration of contracts for performers of R&D in industry and government.

Industry Contracts. Industrial R&D in the United States is, of course, motivated by profit. Industry's basic charter from its stockholders is to produce a profit and therefore industrial R&D must also carry this responsibility even though the potential profit from a given program may be long-range (5-15 years). One incentive for an industrial research laboratory to participate as a performing group for a sponsor is the long-term profit.

An industrial R&D manager has to consider whether or not a contractual R&D opportunity can be justified on the basis of an eventual opportunity for the company to make a profit. The dollar value of the performance fee (conventionally 5-20 percent of the contract value) is often insufficient justification for a private firm to provide the required services unless the manager is attempting to maintain staff during a period of business recession in which staff reductions are necessitated because of a reduced R&D budget.

Frequently, contractual opportunities involving basic research are attractive to expand the overall capabilities and background knowledge of the staff. Industrial R&D budgets for such fundamental research, however, are frequently lean in comparison with the applied or developmental budgets because the chance for pay-out on the R&D investment is usually low or long range.

A number of companies look on government contracts as a means of maintaining their technological leadership in an important field. Competing for such contracts can also have defensive aspects: a firm recognizes that if it does not obtain its share of such sponsored research, its competitors will, and thus enhance their capabilities.

In applied research, a manager sometimes sees opportunities in a contractual program carried out for another organization which could lead to manufacture of a new product or development of a new process. A most obvious incentive, of course, is found when the contractee, frequently a government agency, is a prospective purchaser of the product or process to be developed through the contract R&D. For his company to participate in the commercialization of the process, however, particularly when third parties are the potential customers, the manager usually has to obtain proprietary rights on inventions that could be made during the performance of the contract. If the contractee does not provide this incentive, it may not be possible to negotiate a contract. Frequently, contracts may be negotiated in which a performing group receives a nonexclusive, royalty-free license to practice the inventions. The R&D manager then may see advantages in obtaining first hand the fruits of the research and thus in achieving valuable lead time to commercialization, even though his license is not exclusive and he can eventually anticipate competition.

The format of contracts in which an industrial R&D organization could or would participate is to a degree dictated by the contracting organization. Prime contractees for employing industrial R&D skills are the federal (and to much lesser extent state) government and industry itself. Federal contracting procedures are complex and somewhat rigid. An industry-to-industry contract, on the other hand, tends to be more flexible.

Federal Government Contracts. The primary variable determining the selection of the type of contract for R&D procurement by the federal government is the degree of uncertainty in the government's ability to describe exactly what it wants. When an agency's needs can be fully specified, procurement can be made by advertised methods, and the contract can be firm-fixed price. On the other hand, where its needs and the method of satisfying them can be described in only general terms, procurement is sometimes best accomplished by negotiation, and the contractual relationship should be as flexible as possible. R&D procurement falls typically within this latter category.

At the basic research end of the R&D spectrum, there is less sensitivity to the contract type since goals are generalized and risks of failing to meet objectives are low. The converse is the case for advanced development, or where deliverable hardware is concerned. To oversimplify, the selection of contract type for R&D reflects two principles:

1. The fixed-price contract is normally not suitable because of the basic unpredictability of risk and the outcome of results.

2. A cost-reimbursable contract is preferred where the sponsor expects to have some role in the direction of the work to be performed.

These principles do not take into consideration other options open to the parties to enhance the performance of necessary services. For example, a fixed-price contract may be appropriate for the performance of R&D if the degree of risk is reasonably known by the parties, or if other plans are available to describe adequately the relationship between performer and sponsor. Thus, when the performer is obligated only to provide a stipulated level of effort and to use his best efforts to achieve some R&D objective, fixed-price contracts work. Conversely, inappropriate use of a cost-reimbursable contract can fail to provide a suitable incentive for the effective performance of work. The administrative expense of cost-reimbursable and fixed-price contracts, by the way, differ substantially. For cost-reimbursable contracts, the burden of cost analysis in proposal preparation and the accounting procedures in performance auditing often eliminate many competent sources, particularly small business, from competition. This factor should be a consideration in the selection of contract type.

Contracts are oriented to agency needs. Appropriation of funds is made by Congress in connection with the budgets of the Executive Branch. Types of contracts that can be negotiated are:

1. Cost only
2. Cost plus fixed fee
3. Cost sharing
4. Cost plus incentive fee
5. Cost plus award fee
6. Firm-fixed price.

Usually cost-plus-fixed-fee or cost-sharing contracts are negotiated with industrial research organizations. The cost-plus-fixed-fee contract is a reimbursement contract which also provides for the payment of a fixed fee to the contractor. General and administrative costs are also reimbursable. The fixed fee (not to exceed 15 percent of the contract value on R&D contracts), once negotiated, does not vary but may be adjusted as a result of subsequent changes in the tasks defined by the contract.

In a cost-sharing contract, the contractor agrees to share the cost of the program. Sharing of costs can vary from sacrifice of fee to a substantial sharing of the overall program costs. In such cases, a contractor can receive rights to inventions and licensing rights. Cost-sharing contracts are more commonly used for programs in an advanced state of development (pilot or demonstration plant scale).

Cost-plus-incentive-fee and cost-plus-award-fee contracts are usually not negotiated for small R&D contracts. Contracts of this type offer the contractor an opportunity to obtain a higher fee based on shortening the period of performance, surpassing predetermined performance goals, reducing cost, and the like, and are most commonly used for hardware or product production contracts.

R&D contract negotiations between industrial organizations are, as previously stated, relatively flexible. Contracts fall into the fixed price, cost, or joint categories with a variety of shadings for recovery of costs, fees, and administrative expense. Patents and inventions, licensing rights, and the like, can accrue to the account of the performing group or to the sponsor, depending on the terms of amutually satisfactory agreement. Frequently, these rights are shared.

The federal government contracts internally on an agency-to-agency basis as desirable. This transfer of funds is handled by a contractual mechanism; however, fees cannot be charged by the performing group. The internal administration and auditing procedures are simplified considerably in contrast to a government-industry contractual agreement.

Some government laboratories have contracted as a performing group for industry; however, the amount of research done by this mechanism is less than 0.1 percent. More frequently, a government-sponsored contract to industry requires the services of a government laboratory for performance of a portion of the total work. In this situation, the industrial group frequently sub-contracts to the government group, usually through a fixed-price or cost (no fee) -type contract. Thus, contractual funds flow from the sponsoring government agency to the industrial organization and back to the government for that portion of the work it performs.

Current Problems of Federal R&D Contracts. Although government contract procedures have been refined over the years, there is increasing sentiment that the effectiveness of the government contract mechanism in stimulating innovation has been decreasing. Three major reasons are:

1. Funds for unsolicited proposals, for the support oy truly novel, high-risk research, are limited. Such support was especially useful for smaller companies.

2. It may take a year or more to obtain final government clearance to fund a program. One agency requires 17 different approvals before a research contract can start.

3. The management and control systems for administering contracts are so complex and cumbersome that it is uneconomical for both small and large companies to perform contract work.

A real danger is that the government will increasingly rely on its own laboratories who now compete vigorously for government contracts other than those from their own sponsors, and on companies predominantly engaged in the defense and aerospace industries who have little experience in civilian markets. These organizations, which may be technically competent do not have the marketing and manufacturing skills to commercialize successfully the results of their research.[67]

Monitoring and Reporting of Contract Research. Obviously, the funding agencies of the government must measure the progress of the technical effort and appraise the performance of the contract. Such monitoring can involve evaluation of four measures of research progress:

1. Fidelity (or relevance): is the work being performed as directed by the contract or the project officers, and are the activities being done under the contract authority necessary to the achievement of the established objective?

2. Quality: are the professional standards associated with the proper accomplishment of such work being met?

3. Rate of performance: is the work being performed at a satisfactory pace when compared with a realistic standard for accomplishment? This implies, of course, that a standard can be defined.

4. Prospectiveness: do results to date represent a reasonable basis for concluding that continued work along the current course is desirable? Or do the results imply the need for undertaking a different course of action? If the need for a change it indicated, are adequate data being accumulated to allow selection of a more fruitful course of action? Will additional efforts be required to supplement those in progress? Is the overall program being aided or delayed by the progress

in a single project? Measuring prospectiveness is difficult, yet important, throughout the management structure.

Monitoring can be continuous or periodic, formal or informal. "Tight" monitoring relies upon continuous review by formal techniques, while "loose" monitoring utilizes intermittent review by informal techniques.

In continuous monitoring, an uninterrupted flow of information is acquired and compared against target achievement criteria. This approach to monitoring is most applicable to critical phases of programs, such as during the start-up of a new program.

In intermittent monitoring, data on progress are acquired on an irregular schedule or with a scheduled frequency. Intermittent monitoring is an efficient approach to monitoring programs that vary considerably in time and complexity. It fosters the exercise of self-direction since between reporting periods the contractor is allowed almost full freedom of action.

The informal approach may be appropriate for small contracts or single projects, but is generally unacceptable and ineffective for large programs requiring a high degree of coordination among a number of persons. While informal monitoring can be of value to large programs, the complexity and importance of such programs justify greater formality.

A major tool of monitoring is the reports submitted by the contractor. In such reports, it is important to avoid confusing the condition of change with that of progress. For example, a reporting of man-hours expended reflects a condition of change but does not necessarily reflect a measure of progress. To be of value, reports must reflect measures of progress towards objectives. However, unless contract objectives are carefully defined during baseline negotiations, standards for anticipated progress cannot be readily formulated. If objectives are not clearly stated and reporting requirements tailored to provide relevant information, the reports may merely present descriptions of methodology or resource utilization without useful interpretation. As part of the contract, a project officer usually develops with the contractor a plan that specifies the types and frequency of reports to be submitted.

In sum, the following points seem pertinent concerning monitoring and reporting:

1. Each project officer should periodically review the basic program work statement to determine if day-to-day redirections of effort have rendered it obsolete.

2. While the information called for in the plan for reporting need not be exhaustive, it should include key indicators of progress.

3. In administering the monitoring function, the project officer must close the loop, that is, take corrective action whenever the contractor fails.

4. Variations in the contract mechanism used to support R&D place differing monitoring demands on both the government and its contractors, but both parties must be effective evaluators of the work in progress.

Evaluation of R&D Performance. Federal agency R&D programs are evaluated at several levels. Individual agencies continuously evaluate their R&D efforts internally; the results are not normally available to the general public. Outside scientists and engineers are frequently used to give objectivity to these internal evaluations. Significant evaluations are also done by groups outside the agency, notably by Congressional committees. Typically, Congressional committees hold hearings on a given federal R&D effort to see whether the program looks effective and whether the product looks reasonable. This procedure is most common for large and controversial programs.[68] Occasionally, a Congressional group or perhaps even the agency itself employs an outside group for an overall evaluation. The group most commonly asked is NAS.[69]

The heads of most agencies also have advisory committees of experts who meet regularly. Lower level committees may contribute to the strategic decisions of certain major services.[70] The membership of these panels varies widely. Some meet regularly and are apparently highly institutionalized. Some subcommittees responsible for assessing the scientific merit of a proposal are much more informal and consist of a few specialists who are asked to give an individual opinion.[71]

Besides these forms of evaluation, the Government Accounting Office (GAO) and the Congressional Budget Office (CBO) also review federal R&D programs.

Specialized Techniques for Program Control and Evaluation. Certain sophisticated methods have been developed to control and evaluate government programs of great size and complexity. These include Program Planning and Budgeting System (PPBS), Program Evaluation and Review Techniques (PERT), and Policy Research and Analysis (including cost-benefit analysis).[72]

These specialized planning and project review techniques came into use during the early 1960s primarily for exceedingly large development programs in aerospace and related fields. These programs typically were composed of many subcontractors who were geographically dispersed. They required the integration of many subsystems and careful control of sequencing in order to insure success. Such large scale and complex programs simply called for more sophisticated and higher capacity management control systems than had been necessary, and they were practicable only through the incorporation of computerized data processing. Computer control necessitated the analysis of problems into small pieces and precise specification of the relationship among all the pieces--particularly the time when the work was to be completed if the schedule was to be maintained. It is important, however, to distinguish between PERT time plans and the computerized systems used to keep track of the implementation of a specific program. Few R&D programs are big enough to warrant elaborate computerized information processing. Consequently, virtually no use is made of these procedures in research programs--even in applied research programs--and only very limited use of them in development programs. Few development programs are large enough to require a computer. Furthermore, R&D programs neither permit nor warrant rigid scheduling of the entire sequence of work to be accomplished.[73]

PPBS methodology applies to the identification and specification of technical programs within a framework of broad strategic guidelines or goals. Like many of these techniques, this methodology was devised for defense applications. Introduced into DOD in the early 1960s, PPBS responded to the need for better allocation of resources within the Department, for clearer specification of objectives, and for improved analysis of alternative ways of achieving these objectives. In 1965 the PPBS system was extended to civilian agencies. Although PPBS as such is no longer used, the concepts and many of the techniques that it employed are still in use.

PPBS was unwieldy, complex, and disposed toward excessive paperwork. While it did stimulate analytic discipline in considering problems, it lacked credibility and support from Congress. Moreover, PPBS stressed quantitative analysis and thus tended to be frustrated when it encountered the kind of uncertainty which accompanies both social goals and scientific research. PERT was somewhat different, being less a quantitative method of policy analysis and more a systematic program management technique for reaching technological targets within constraints of money, time, and logistics. Its best use was in crash development programs, but in simplified form it has been useful in other multi-dimensional projects with many variables to be concerted and scheduled.[74]

The discipline required to prepare a PERT program can be valuable. Meticulous examination of all of the work which must be done in a proposed R&D program provides sharper insights into the most efficient sequencing and into the time required for, and relative difficulty of, various aspects of the program. Having gone through this exercise and diagrammed the flow of work and the time sequence required, managers can usually achieve the necessary control of program implementation by such manual methods as progress reports and face-to-face review sessions.[75]

A new tool, Technology Assessment, evaluates the probable impact of a new technology generated by R&D through risk-benefit analysis, cost-benefit analysis, and environmental impact analysis. Technology Assessment techniques were developed in response to the National Environmental Policy Act of 1970. This law requires that every major action by the federal government or by persons or organizations using federal funds must be accompanied by a statement evaluating its impacts on the social, economic, and physical environment. It means no action can be taken until all of the negative and positive impacts on the area, its population, and its aesthetic quality have been documented. Both quantifiable and non-quantifiable impacts must be determined, and the interested parties have a right to be consulted and to intervene through the courts. State governments have enacted similar laws for their jurisdictions. Impact statements are now a way of life. It is not unusual to discover that a large and complex technological project will require an environmental impact study which itself may cost several million dollars and delay the project up to five years while program content is improved. These studies are necessarily inter-disciplinary, and they encounter difficult conceptual and methodological problems of quantification of environmental impacts.[76]

Another technique, Policy Research and Analysis, has played an increasing role during the last decade in the analysis of federal government policies and programs. Numerous phrases have been used to describe the techniques of Policy Research and Analysis: cost-benefit analysis, cost-effectiveness analysis, systems analysis, program analysis, planning-programming-budgeting, program evaluation. They differ in emphasis but share a common concern for clearly specified objectives, operational definitions of objectives, and measurement of success in reaching objectives. Unfortunately, this common concern sometimes becomes lost in an attempt to define and differentiate the many approaches and techniques. In a broader sense, the term "policy studies" can be used to encompass the approaches to systematic research and analysis relating to government policies and programs, including research on the policy process itself.[77]

Because program analysis was an important part of the PPBS concept, the distinction should perhaps be noted between program analysis and program evaluation. Although they share many features, program evaluation is retrospective whereas program analysis is prospective. Program analysis looks at a problem and considers alternative ways of achieving solutions, given whatever goals have been established. Program analysis requires predictions which are drawn from cause-effect relationships derived from predictive social science theory. Thus program analysis is largely the application of social science theory, whether or not empirically tested and proved. Program evaluation likewise uses social science theory but its primary emphasis is on empirical investigation (what happened in contrast to what will happen), using theory to set up the empirical investigation. Program evaluation is a more continuing function, involving large efforts of data gathering, and resulting in incremental changes to improve the program. Program analysis may use the results of previous program evaluations, but generally considers a wider range of alternatives to present programs.[78]

One special subcase of Policy Research and Analysis is cost-benefit analysis, sometimes called cost-effectiveness. The objective of cost-benefit analysis is to evaluate one or a series of alternative objectives in comparison with the cost of their attainment. The purpose is to allocate limited resources to maximize their productivity. In general, this procedure is no more than the application of marginal productivity analysis found in classical economic theory. The circumstances which generate the need for cost-benefit analysis are those in which desirable goals outstrip resources. But the problem is more than one of simply deciding which goals, if reached, would yield more benefits than the cost of reaching them. The organization is typically faced with a larger number of attractive possibilities than it has resources to pursue. Consequently some desirable goals will not be pursued.[79]

As commonly understood, formal cost-benefit analytical techniques are not widely used to administer R&D in the United States, except in advanced military and aerospace technology. They have, however, long been applied in water resource management. Despite continuing attempts to develop rigorous analytical techniques, conventional cost-effectiveness methods are rarely employed, if at all, in fundamental research and only occasionally in either applied or developmental research because of the inherent limitations upon quantification of either costs or benefits. However, efforts continue to develop useful techniques. Such an analysis is extremely useful and widely practiced as an approach to resolving larger problems of resource allocation to industrial or societal needs in which R&D is one element.[80]

The Government as Purchaser of the Results of Research

In addition to its role as performer and funder of R&D, the government is a major purchaser of R&D results. A look at the influence of government on innovation in the past half century suggests strongly that government is especially effective when it has offered to purchase products and services which are the result of technological advances.

Utterbach and Murray, in a study of how DOD has influenced innovation in the electronics industry[81], find that government purchases of technically sophisticated products both supported and contributed to the early marketing of products such as jet aircraft, computers, and semi-conductors. It is well documented that in the period from approximately 1945 to 1960, government purchases of computers provided a vital flow of funds and encouragement to the infant industry. In the health care industry, a Rand Corporation review of federal demonstration projects has cited the success of the Veterans Administration in providing an accessible and aggregated market for hydraulic knee prosthetic devices.[82]

To explore the stimulative effects of government more thoroughly, the Experimental Technology Incentives Program (ETIP) of DOC funded several small projects. As an example, they persuaded the government to prepare specifications for a silent lawn mower. The expectation is, of course, that companies developing such a device for sale to the government could also sell it profitably on the civilian market. It is not yet established whether these ETIP programs, which have not been heavily funded, can contribute significantly to our understanding of the government's role as a purchaser.[83]

The Government as Regulator

Finally, in our discussion of the role of the federal government in planning and managing R&D, we turn to the influence of government regulations. Such regulations can create opportunities for, as well as barriers to, innovation. The patent system (see also chapter 4, pp. 164-169) and the tax structure directly control aspects of innovation; regulatory bodies such as the Federal Communication Commission and the Interstate Commerce Commission, and agencies involved in antitrust policy influence innovation indirectly by the control of firm and industry structure, profit rates, and accounting practices. Although the primary concern of such agencies is not innovation, such controls act to modify the economic arrangements involved in innovation. Moreover, the federal government has traditionally been responsible for intervening when necessary to protect the health and safety of its citizens. The effects of regulation are overlapping and varied. A few examples illustrate some of the results of regulation.

As we have noted, the patent system serves as a powerful stimulus to innovation in the United States. Antitrust policy interacts with--and sometimes conflicts with--the patent system. Patent policy encourages the granting of limited monopolies to inventions, while antitrust policy is designed to break up industrial monopolies which may or may not be based upon patent protection. The courts have recently attempted to reduce the conflict between patent and antitrust policies by requiring the compulsory licensing of patents as a means of reducing the monopoly power of a firm. Industry, however, resists vigorously efforts to diminish the value of an issued patent in conferring a temporary monopoly during which time it can exploit its innovation and recoup some or all of its investment.

Tax policies affect innovation in two ways. First, taxation provides the funds used by the federal government in direct support of R&D. Second, tax policy may stimulate or impede the availability of private funds for the innovation process. At present, industrial R&D can be treated as a business expense. This means that if the firm is profitable, the government effectively pays half of the cost simply by not taxing that portion of the profits which are plowed back into R&D. This tax policy does not derive from any special status for innovativeness; R&D expenses are simply treated as normal operating costs. Naturally, there have been appeals for a tax policy that encourages innovation by allowing larger deductions for R&D and also by faster tax write-off of depreciation on new equipment.[84]

In the beginning of the 19th century, the government set standards for steamboat boilers after frequent explosions caused accidents on the river. Other regulations followed. For example, early in the present century legislation was enacted to insure against contamination of food and the harmful side effects of drugs. Indeed, the problem of deciding what new pharmaceutical products can be introduced to the market has received increasing increasing attention over the years. At first the manufacturer was required to prove only that the new product was safe under the conditions of use. But in the early 1960s the additional requirement was legislated that it must also be proved effective to the satisfaction of the Food and Drug Administration (FDA). This requirement has added a new dimension to drug regulation since subtle physiological differences among the prospective patients may make clear proof of effectiveness under all conditions difficult. FDA sets the requirements for drug testing; proof of safety must be extremely strong before any testing on humans is permitted and large masses of data must be assembled and thoroughly analyzed before the firm which has developed the product is permitted to introduce it to the market. Even after introduction, if any evidence whatsoever of unforeseen harmful side effects is observed, FDA has the authority to withdraw the drug. Recently, FDA has also been authorized to inspect the testing facilities of all companies working in drug development. For these reasons, generally 3 to 10 years are required beyond the time at which a new chemical agent has been synthesized and demonstrated to be effective on animals before it can be broadly marketed. The costs run into many millions of dollars.

Obviously, only companies with substantial financial resources and large technical staffs can undertake such efforts. Another result of these rigorous requirements is that many drugs considered useful in other countries are unavailable in the United States for a number of years after they are introduced abroad. A similar situation exists with agricultural chemicals (also called pesticides, or plant protection agents). EPA is responsible for registration of these substances. Safety and efficacy must be proved, and often the complete metabolic pathway--how the chemical is degraded in the plant and in the soil--must be worked out. Thus the introduction of these new products is also time consuming and costly.

Recently, a Toxic Substances Control Act was enacted which requires firms in the chemical industry to inform EPA when they are going to introduce a new chemical to manufacture or to the markets, along with all information about any harmful effects of the chemical on human beings, on animals, or on the environment as a whole. EPA is empowered to require additional testing and proof of safety before the chemical can be made or sold. It is too early to tell what effect these regulations will have on the development and introduction of new products, always a major source of growth and profitability to the chemical and allied industries, but there is concern that innovation may be considerably slowed down. In addition to drugs and various consumer products, medical devices have recently become subject to safety review by government agencies.

Drawing heavily upon Rand Corporation studies cited earlier, Abernathy and Chakrabarthy have reviewed the ways in which government intervenes in industrial innovation, including regulatory action.[85] They distinguish between direct government action to create useful new technology and thus bring about change (technology-push) and government action which modifies markets and specifies new product characteristics (technology-pull). They find that the use of federal funding to create sophisticated technology (technology-push) such as nuclear ships for commercial use, radically new building materials, or novel means of personal transportation, has been generally ineffective in creating items for widespread commercial application. Better results have been achieved when the government has helped to provide better market aggregation when user needs were already clear, even when the technology in question was simple (technology-pull). Examples are expressway surveillance, the prosthetic knee, and poultry waste processing. These authors, in a further study on the interaction of government regulators and the automobile industry in auto safety, pollution control, and fuel economy, conclude that, in spite of continuing agruments between industry and the government agencies about cost versus benefit, the overall system by which government sets targets which it says must be met at some specific time and then relies on industry to create and put into use the necessary technology is working reasonably well. They see little justification for the government itself to become involved in massive scale development of sophisticated new technology such as novel propulsion systems.

In sum, then, government regulation can both benefit and impede. Legislation to control air pollution has, for example, enlarged markets for monitoring instruments, for catalysts to convert auto pollutants to harmless substances, and for large installations to scrub sulphur oxides from stack gas. The regulations also benefit existing industries, in spite of the burden of new control devices, by reducing the threat of competition from entirely new companies or companies from other industries which could not meet the regulations. Conversely, of course, the regulations may also impede innovation. The cost for a company with no previous background of research to enter, for example, pharmaceuticals or agricultural chemicals has become almost prohibitive. It will probably be many years before the costs imposed by government regulations on industry can be accurately measured.

THE STATE GOVERNMENTS

The individual states are not as important in their direct support of R&D in the United States as the federal government, but their activities do deserve a brief look. In 1975 the states contributed about 10 percent of the R&D expenditures made by universities.[86] Their support of public universities, however, makes the states an important element in the health of the R&D effort. In addition, although expenditures by state agencies themselves are still small, amounting to only $265 million in 1973, with the two most populous states accounting for over a third, such expenditures grew three-fold in 10 years in constant dollars.[87]

Since the federal government provides matching funds for many state R&D activities, its preferences for research direction are naturally influential.

Federal support of R&D programs of state and local governments has been steadily rising. Today about 50 percent of state and local government R&D activities are federally funded. Nevertheless, the scale of activity remains small. Expenditures by state governments on R&D amount to little more than half of one percent of total state budget expenditure. In contrast, federal support of R&D activities is approximately 53 percent of total R&D expenditures and 10 percent of the total federal budget.[88]

At present, there is growing effort to bring science and technology to bear on the solutions of domestic civil sector problems which are primarily the responsibility of state and local governments. Accordingly, more emphasis is being placed on transferring money and responsibility for government R&D programs to state and local authorities. Since systems management and program budgeting have taken limited hold in state and local government, efforts are also being made to enhance their capacity to plan and manage the applications of technology. An Intergovernmental Science Program at NSF has been assisting both executive and legislative branches of state government to establish science advisory offices and staffs. During the past five years, all of the states have established science and technology advisors. Together they constitute a newly formed organization, the National Governors' Council on Science and Technology. The Department of Transportation and the Department of Justice have developed new technology-sharing programs. Other channels for expanding federal-state-local partnerships in applied research and development include making federal laboratories available for state and local government R&D.[89]

States use two mechanisms to perform R&D. The first is the performance of R&D by personnel employed by the state governmental bodies, that is, in-house research. This mode is used chiefly for small short-term R&D and represents only a minor fraction of the R&D budget. The second mechanism is the use of contracts. The contracting mode includes the funding of both solicited and unsolicited proposals for work to be performed by either public or private sector organizations. It should be noted that, in general, states restrict their contracting to organizations within the state.

State-supported R&D activities are largely concerned with education, agriculture, and environmental protection. Much state funding is devoted to applied R&D at the land-grant college in the particular state. A considerable amount goes to institutions commonly called Engineering Experiment Stations which are affiliated with the engineering schools of public universities and colleges and which carry out work for both public and private bodies in the state and elsewhere on either a grant or a contract basis. Most states also support, in any given year, a number of economic research projects aimed usually at exploiting their natural resources and finding ways to attract more tax-paying industry. Such projects are usually carried out at the universities in the state or by contract research institutes in the state or in the region.

Through their representatives in Congress and through the governors and their staffs, the states lobby vigorously for federal research money and for the establishment of new federal research facilities in their territory.

Recently, a few states have taken especially strong initiatives to promote and utilize research in applied science and economics. The government of the State of North Carolina was the driving force in establishing the Research Triangle Foundation which, in a research park, groups together laboratories of various private firms which have been attracted there, along with the laboratories of several federal agencies in close proximity to two large public and one large private university. One of the main groups in the Research Triangle Institute works on problems of regional planning.[90]

THE RELATIONSHIP OF GOVERNMENT TO OTHER PERFORMERS OF RESEARCH

Government in the United States helps assure a climate in which science and technology can grow. It works, as we saw in this chapter, on many levels, both directly and indirectly. The major performers of R&D, however, are the universities and industries. The universities, either private or public, provide the training ground for scientists and engineers. Professors also conduct research, funded both by the government and private industry. They provide other R&D services to both government and industry. Private industry itself is the largest performer and user of R&D in the United States. Industries generate innovation as a function of the market mechanism, through competitive enterprise. In the next chapters we turn to a detailed discussion of planning and management of R&D in the universities and especially in private industry to parallel our concern with government systems in this chapter.

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III RESEARCH IN THE UNIVERSITIES

INTRODUCTION

There is no such thing as "the American University" in the sense that there is a typical British, French, or Swedish university. In the United States there are approximately 2000 institutions offering education beyond secondary school level. Some have tens of thousands of students, some a few hundred. Some are supported largely by the states, some are private. There is not even a single satisfactory criterion as to whether a particular university should be categorized as a "research university." In 1970, 220 institutions awarded doctoral degrees, which conventionally connotes an original research accomplishment. Five hundred eighty-five received federal grants for research. On the other hand, the eminent Carnegie Commission on Higher Education classified 94 institutions as research universities.[1]

Similarly, research at universities is a heterogeneous endeavor. Some is carried out in traditional departments, some in interdisciplinary research centers, some in experiment stations, some in affiliated research hospitals, and some in various independent laboratories and small institutes supported by federal or state monies or private endowments. In contrast to many other countries, the United States has not evolved a system of large, more or less autonomous, research institutes to carry out its basic research, but has depended instead upon its universities. After World War II, in which university research and university faculties contributed greatly to the nation's defense effort, there was a great surge in university spending for basic research that has lasted over three decades.[2]

In 1977, R&D expenditures in universities reached $4.1 billion, of which federal funds accounted for two-thirds. (Five agencies, DOD, NSF, NASA, the NIH, and ERDA, accounted for over 80% of this federal support.) The proportion of funding from federal sources has been declining gradually for the past 10 years, and the universities are relying more heavily on other funding sources such as private foundations and industry and on their own institutional funds (Tables 4-1 and 4-2). It is noteworthy that in spite of complaints from the academic community about the unavailability of money for needed research, the growth in spending on university R&D in the past 10 years has been higher than the expansion of the economy as a whole or the increase in total expenditures for higher education.[3]

Universities perform over half the basic research conducted in the United States. Spending for applied research, however, is becoming a larger fraction of the university effort, increasing by about 15% per year over the past five years to the point at which it now accounts for a fourth of the total. As is to be expected, university spending on development programs is relatively insignificant. In basic research, federal support accounts for about three-fifths of what the universities perform, but funds have not been growing rapidly in terms of constant dollars. The top 100 universities spent 83% of the total for academic R&D and received about 85% of the federal funding.

University research is heavily concentrated in the life sciences, which account for slightly over half of all their R&D expenditures. Physical sciences and engineering account for about 10% each. Mathematical and computer sciences, psychology, environmental sciences, and the social sciences make up most of the rest.[4]

TABLE 3-1

R&D EXPENDITURES AT UNIVERSITIES AND COLLEGES, BY SOURCE AND CHARACTER OF WORK: FY 1976 AND 1977

SOURCE AND CHARACTER	TOTAL 1976	TOTAL 1977
Total R&D Expenditures	$3,730,688	$4,064,220
Source of Funds:		
Federal Government	2,501,139	2,716,767
State Government	370,549	362,255
Local Government	15,219	13,400
Foundations & Voluntary Health Agencies	182,709	191,737
Industry	123,519	139,149
Institutional Funds	435,272	517,681
All Other Outside Sources	102,281	123,231

TABLE 3-1 (Continued)

State and Local Government Combined	385,768	375,655
Character of Work:		
Basic Research	2,547,494	2,787,546
Applied Research	1,014,893	1,067,421
Development	168,301	209,253

Source: National Science Foundation

TABLE 3-2

TOTAL AND FEDERALLY FINANCED R&D EXPENDITURES IN THE SCIENCES AND ENGINEERING AT UNIVERSITIES AND COLLEGES, IN CURRENT AND CONSTANT DOLLARS: FY 1970-77

(in billions)

	CURRENT DOLLARS			CONSTANT DOLLARS		
YEAR	TOTAL	FEDERAL	NONFEDERAL	TOTAL	FEDERAL	NONFEDERAL
1970	2.3	1.6	.7	2.6	1.8	.8
1971	2.5	1.7	.78	2.6	1.8	.81
1972	2.7	1.8	.84	2.7	1.8	.84
1973	2.9	2.0	.90	2.8	2.0	.86
1974	3.0	2.0	.99	2.7	1.8	.88
1975	3.4	2.3	1.1	2.7	1.8	.9
1976	3.7	2.5	1.2	2.8	1.9	.9
1977	4.1	2.7	1.35	2.9	1.9	.95

Source: National Science Foundation

ORGANIZATION AND STRUCTURE OF UNIVERSITY RESEARCH

Research in universities is based upon the freedom of the investigator to pursue studies in his chosen field with as few constraints as practicable. His advancement and recognition are determined by the judgment of his peers in his university, in other universities, and in other institutions of equivalent standing. The professor has traditionally resisted any incursions of the university administration in his domain, the scientist no less than his colleagues in the humanities. But the great complexities of the research funding and reporting mechanisms have led universities to seek new administrative structures which can provide an overview of the university's R&D and relieve the active researcher of some of his burdens in obtaining and administering the funding of his efforts.

Administrative responsibility for the university is typically in the hands of the president, who operates with a staff of vice presidents to deal with administrative matters and who has reporting to him a series of academic deans. These deans in turn administer the individual disciplinary departments which contain within them the university faculties who carry out the teaching and research.

The key person for carrying out research in the universities is the professor, who generates research ideas and supervises the study. The actual research frequently involves a group of people working with the professor, composed of graduate students and research associates who are usually studying at the postdoctoral level.

Lines of authority to the professor are somewhat complex. Some supervision of research occurs through the college deans and department chairmen who concern themselves with such questions as space for research, relative responsibilities for teaching and research, and allocation of university and departmental funds. However, the president's office may communicate directly to the professor, frequently through an officer like vice president for research. This same officer also communicates on research policy problems with college deans and with department chairmen.

As research administrations have become more important, major universities have assembled staffs of several dozen people. They interpret their mission as one of serving the researcher. Among the functions they may perform are keeping active researchers informed about invitations for proposals from sources of funding, providing some assistance with draft applications, and making sure that applications comply with all legal requirements.[5]

It is important that the universities maintain some reservoir of funds that can serve as seed money to provide initial support for young promising faculty members who are just beginning their research careers and who have not established contacts with major sources of funding.

Another trend of recent years which runs counter to the tradition of the highly individualistic researcher in the university is the formation--frequently with government encouragement--of multidisciplinary research programs.[6] In these programs, a group of research specialists with different skills collaborate in some area of research that may be either broadly or narrowly defined. The Materials Science Research Centers established at a number of universities are a notable example. Such programs are not implemented without creating certain stress in the university value system. The professor's primary loyalty is to his department, and usually his academic advancement and recognition depend upon the peer judgment in his department. The young doctoral candidate may legitimately doubt whether his publications submitted as a representative of a multidisciplinary center will be accorded the esteem attached to those coming from a well established department of many years' standing. But such programs, in spite of all the problems, seem likely to continue and expand. Many of them, even those with long-range orientation, have elements of applied research, thus appealing to many professors, especially of the younger generation, who wish their research to be "relevant" to the problems of the nation and society as a whole. Recognition of the complexity and the great technical challenge of such problems as environmental pollution and long-term sources of inexpensive energy have contributed greatly to this emphasis. Indeed, fears have been voiced that capable investigators are being diverted from sound basic research for which they are well qualified to rather second-rate applied research best performed outside the university.[7]

UNIVERSITY-GOVERNMENT RELATIONSHIPS

Faculty members who have attained distinction through their research and publications work with various government bodies in a number of ways. Naturally they serve on peer review panels which advise about awards of grants for basic research in their own fields. They also serve on government committees which advise on a wide variety of topics including long-range technical strategies and the allocation of resources among fields of scientific and technological endeavor. In such a capacity they have advantages over engineers and scientists in private firms who may have equivalent qualifications because the government is much concerned--some feel unduly--about conflicts of interest in which advice rendered by the expert might benefit his company. Recognized authorities are frequently invited to testify before Congressional committees considering new legislation or conducting investigations. Of course, the professor may serve as technical consultant on government projects as well as a policy advisor.

It is by no means uncommon for professors to take leaves of absence from their universities to serve for a few years in a senior government post. Though some problems occasionally arise, "re-entry" into the academic life is considerably easier than into a corporation.

UNIVERSITY-INDUSTRY RELATIONS

Industry depends heavily on research universities for two vital contributions to its well-being: a continuing supply of well-trained graduates for technical staff from which many of its future managers will be drawn and fundamental research which will form the basis for industry's future technical accomplishments. Although generalization is difficult, it is probable that from the end of World War II until the mid-1970s, the interaction between the university and the industrial research communities was not as warm or as effective as before the War when both establishments were much smaller. Government funding of university research was liberal, emphasizing fundamental investigations and contributions to knowledge, and did little to encourage any attempts to relate the research coming out of the universities to any ultimate practical application. Moreover, the leading centers of graduate education in the biological and physical sciences --in contrast to engineering--have traditionally considered that they were training their students for careers in university teaching and research, admitting that a small fraction would find employment in industry.

In recent years, as we have seen, increases in government funding have been much slower and investigators have been glad to obtain even modest support from industry sources. Undoubtedly more important, however, has been the increasing concern in the university with economic and societal relevance as discussed above. There are a number of ways in which the university researcher develops relationships with counterparts in industrial firms.

Consulting

For many years, university departments have permitted and even encouraged professors to spend several days a month as consultants to corporations carrying on research in which the professors' expertise is valuable. It is widely agreed that this arrangement can be advantageous to both parties. The corporation obtains fresh ideas and viewpoints; the professor obtains a better understanding of how business operates and how his own research can find some application to the benefit of society and to his own personal and professional satisfaction. Distinguished professors may be asked to serve on the boards of directors of major firms. A few with a bent for entrepreneurship may help establish new companies and even serve as parttime managers of their research efforts. This has occurred most often in the electronics and pharmaceutical industries.

Applied Research

In pursuing applied research supported by non-industry sources, the university researcher usually seeks some guidance from industry sources, either formal or informal, about how to make the results most useful. He usually attempts also to publicize the results obtained and takes an active interest in promoting their commercial exploitation. University research directly supported by company grants or contracts (as distinguished from company grants for graduate fellowships or general university purposes) is not a large component of research funding, but its importance in bringing industry and the university closer may well be greater than the absolute funding level might indicate. These arrangements are not without problems. If any significant invention is possible as a result of the particular research, the company seeks some reward for its financial support in the form of proprietary protection, usually via patents, while the university undoubtedly insists upon freedom to publish. If both sides are reasonable and understand the value system of the other, these matters can usually be satisfactorily resolved.

Collaborative Research and Temporary Employment of Faculty in Industry

New mechanisms and modifications of old ones are being explored to focus the best attributes of university and industry research on problems of common interest. DOE is actively encouraging industrial and university groups to work together on research contracts and awards. As another example, one major company has set up a new center for research in certain fields of health care and industrial hazards at a leading university.

It is commonly believed that enabling a university professor to work in an industrial research center for a period of a few months to a year is a most useful form of cross-fertilization. NSF has funded summer programs in which a professor and a company agree on a worthwhile project whose results can be freely published without fear of loss of proprietary protection. Unfortunately, the younger researchers on the faculty who might benefit most from spending, say, six months or more in industry are usually those professors engaged in the competition for tenure appointments which depend largely upon the judgment of the senior faculty about the quality of their publications in their chosen field. They may thus be reluctant to risk leaving their departments for periods of this length.

To perhaps a greater extent than government or industry, the research establishment in the American university is going through a period of transition which is accompanied by stress not experienced for several decades. Many authorities see the need for additional mechanisms--perhaps fostered by government--to promote closer university-industry interaction.

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6. U.S.-U.S.S.R. Joint Working Group in the Field of Science Policy, Subgroup 1--Planning and Management of Research and Development, "U.S. Short Answers to U.S.S.R. Questions Relating to U.S. Research and Development Planning and Management," Washington, D.C., National Science Foundation, December 31, 1974.

7. op. cit., Organization for Economic Cooperation and Development.

IV THE ORGANIZATION OF R&D:

THE PRIVATE SECTOR

INTRODUCTION

In the United States, private industry is the largest performer and user of R&D. In recent years it has also provided about 45-50 percent of the total funds expended on R&D (Tables 5-1 and 5-2). In 1976, the latest year for which accurate data are available, American industry spent $26.7 billion on R&D, and employed in its R&D effort the full-time equivalent of 380,400 engineers and scientists, or about a third of all those skilled professionals it employs. In the 10 year period 1966-76, industrial research spending increased 72 percent; but if the figures are corrected for inflation, the 1976 level is 1.5 percent lower than that of 1966. On the other hand, the work supported by the companies' own funds as opposed to those of the government increased from 46.4 percent to 65.2 percent of the total effort between 1966 and 1976.

R&D performance is concentrated in a few industries with five of them--aircraft and missiles, electrical equipment and communications, machinery, chemicals, and motor vehicles--accounting for almost 80 percent of the total (Tables 5-3 and 5-4). Similarly, federal support of R&D goes to a few industries: almost 80 percent to electrical equipment and communications, aircraft and missiles. Three large R&D performers--machinery (15 percent), chemicals (9 percent), and motor vehicles (12 percent)--receive relatively little of their research funds from the government. In the past five years, the level of industrial research

TABLE 4-1

NATIONAL R&D EXPENDITURES: 1969-70
(in millions)

	CURRENT DOLLARS			CONSTANT (1972) DOLLARS*		
YEAR	TOTAL	FEDERAL	NONFEDERAL	TOTAL	FEDERAL	NONFEDERAL
1969	$25,631	$14,895	$10,736	$29,556	$17,176	$12,380
1970	25,905	14,668	11,237	28,355	16,055	12,300
1971	26,595	14,892	11,703	27,697	15,509	12,188
1972	28,413	15,755	12,658	28,413	15,755	12,658
1973	30,615	16,309	14,306	28,937	15,415	13,522
1974	32,734	16,754	15,980	28,214	14,440	13,774
1975	35,200	18,152	17,048	27,684	14,276	13,408
1976	38,816	19,628	19,188	29,019	14,674	14,345
1977	42,902	21,649	21,253	30,296	15,288	15,008
1978**	47,295	23,815	23,480	31,136	15,678	15,458
1979**	51,630	25,715	25,915	31,772	15,824	15,948

* Based on GNP implicit price deflator

** Estimated

Source: Division of Science Resources Studies/STIA

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TABLE 4-2

R&D FUNDING: EXPENDITURES BY SECTOR
(Constant 1972 dollars based on GNP implicit price deflator)
(in billions)

	AS A SOURCE					
	CURRENT			CONSTANT		
	1977	1978*	1979*	1977	1978*	1979*
Federal	$21.6	$23.8	$25.7	$15.3	$15.7	$15.8
Industry	19.7	21.8	24.0	13.9	14.3	14.8
Universities & Colleges	.9	1.0	1.1	.6	.7	.7
Other	.6	.7	.8	.4	.5	.5
TOTAL	$42.9	$47.3	$51.6	$30.3	$31.1	$31.8

TABLE 4-2 (Continued)

	AS A PERFORMER					
	CURRENT			CONSTANT		
	1977	1978*	1979*	1977	1978*	1979*
Federal	$ 6.1	$ 6.6	$ 6.9	$ 4.3	$ 4.3	$ 4.3
Industry	29.9	33.2	36.8	21.1	21.9	22.6
Universities & Colleges	**5.4	**6.0	**6.4	**3.8	**3.9	**3.9
Other	1.4	1.5	1.6	1.0	1.0	1.0
TOTAL	$42.9	$47.3	$51.6	$30.3	$31.1	$31.8

* Estimates

** Includes expenditures of associated FFRDC's, approximately 25 percent of the amount shown each year.

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Source: Division of Science Resources Studies/STIA

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TABLE 4-3

TOTAL R&D EXPENDITURES OF FIVE LEADING INDUSTRIES: 1965-77
(in millions)

YEAR	CHEMICALS AND ALLIED PRODUCTS	MACHINERY	ELECTRICAL EQUIPMENT AND COMMUNICATION	MOTOR VEHICLES AND OTHER TRANSPORTATION EQUIPMENT	AIRCRAFT AND MISSILES
1974	$2,450	$2,985	$5,011	$2,476	$5,278
1975	2,727	3,196	5,105	2,430	5,713
1976	3,016	3,485	5,635	2,872	6,322
1977	3,266	3,968	5,943	3,419	7,095

Source: Division of Science Resources Studies/STIA

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TABLE 4-4

R&D INTENSITY: FUNDS AS A PERCENT OF OF NET SALES IN SELECTED INDUSTRIES: 1975 AND 1976

(Percent)

	1976	1975
Aircraft & Missiles	12.2	12.7
Electrical Equipment & Communication	6.5	6.5
Professional & Scientific Instruments	6.0	5.9
Machinery	4.8	4.8
Chemicals & Allied Products	3.7	3.7
Motor Vehicles & Motor Vehicle Equipment	3.2	3.5
Average of All Industries	3.0	3.1
Rubber Products	2.4	2.5
Stone, Clay & Glass Products	1.2	1.2
Petroleum Refining & Extraction	.7	.7

Source: National Science Foundation

funding from DOD and NASA has not changed greatly, but funding from other agencies has gradually increased.

The 121 companies which have more than 25,000 employees and which have organized R&D efforts spend 73 percent of the industry total; the top four R&D performers, 20 percent. Furthermore, the large companies receive the greater share of the federal funding.[1]

Company spending as percent of net sales varies less over the course of a few years than the absolute dollar amounts. Total spending for United States industry is running about three percent and company-sponsored spending about two percent of net sales. There is no uniformity between industries in the magnitude of their spending on research. Some industries spend almost nothing while others such as pharmaceuticals, scientific instruments, and aerospace spend between five and 10 percent of their net sales. Within a given industry one also finds a broad range of R&D expenditures.

CORPORATE R&D STRATEGY

Although an industry's spending on research is a good indicator of its technological intensity, one must not conclude that because a particular industry does not spend heavily it is not highly dependent on advanced technology. The electric utility industry has always relied upon its suppliers for equipment which incorporates advanced technical developments. The textile industry has relied upon the chemical companies to keep it competitive in fibers, dyestuffs, sizing agents, etc. The coal industry has largely relied upon government laboratories for long-term research and upon its suppliers of heavy equipment for technical advances.

Each firm has policies and strategies of its own for achieving market position and profitability, and each firm determines its own plans for R&D, its objectives, its scale, and its utility, while taking into account the government's procurement intentions to the extent that they have relevance to the firm and its strategies.[2]

For the most part, American corporations which carry on sizeable programs of R&D are run by professional managers instead of by owners. In fact, the ownership of major companies is widely dispersed. With some oversimplification, one can say that professional managements seek, over a period of years, 1) to maximize the company's profits as a percent of sales and as return on investment employed in the business, 2) to insure a steady and predictable growth of profits (usually calculated as earnings per share of the company's stock) from year to year, and 3) to enhance the value of the company's shares over a reasonable period of time, so that the owners of the shares may realize capital appreciation as well as income from the dividends which the company pays out of its profits each year. Thus the senior managers of the corporation who make the critical strategic decisions determine how much to spend on company research and what kind of research to carry on based upon their perception of how the research will contribute to the management's goals. The R&D program is simply one element of the company's strategy.

The level of a given company's R&D spending is determined by a complex of factors which provide both incentives for higher spending nnd constraints upon the resources allocated to R&D. The weight accorded each factor may vary greatly over a period of years. The following is a list of the chief factors:

1. Knowledge about what other companies in the industry are spending, usually expressed as percent of sales.

2. The company's present profitability, since the research must be paid for out of profits unless the company relies heavily on government contracts for its research

3. The management's understanding of what the research it is doing now and might do in the next few years can contribute to improve profits substantially. Its own experience of whether its research has been productive or disappointing will probably be critical.

   At least in comparison with planned economies, the factor most hindering investments in research (and to a lesser degree, in technically advanced development) is uncertainty about the future value and utility of that research. Extended major investment in research that does not lead to some form of tangible return is obviously difficult in industry, where the opportunity of investing that money in other revenue-gaining alternatives (such as marketing or customer service) is apparent.

4. Avoidance of any action which might cause some drastic decrease in the numbers of engineers and scientists employed in its research and thus seriously damage morale of the organization. Conversely it is generally agreed that staff increases of more than about 15 percent per year cannot be handled efficiently.

5. The "image" of its technological leadership which the corporation presents to other groups in American society, particularly the investing community, the academic community, and the government. Realistically, however, this factor is probably less important today than in the 1950s and 1960s when all research was considered glamorous.

It cannot be overemphasized that a company's strategy in research is greatly influenced by the backgrounds and personal characteristics of the senior managers and the experience over the years of both their industries and their companies in investing in technological development. One management may wish to pioneer technological advances. Another may decide to establish a position in a particular technical area only after the promise of the technology has been clearly demonstrated by others. In fact, the "fleet-footed second," the company which quickly follows the lead of others, has often been quite successful in American business. Some managements insist that almost all R&D expenditures be devoted to protecting existing markets in which the company has established a position of leadership. Others are aggressive in seeking to diversify their businesses through research. Additional elements of the company's strategy may be the licensing of useful technology from other firms or research institutions in the United States or abroad or even the acquisition of small companies which have themselves developed useful advanced technology but lack the financial, marketing, or managerial capabilities to exploit it to maximum advantage.

In all progressive companies the senior managers of research operations participate in discussions about corporate strategies and their demands upon the company's R&D program. It is these managers' function to translate decisions reached into an effective, comprehensive research endeavor which will most effectively utilize the money and the facilities allocated to R&D and, even more important, the skilled technical personnel already in the company or who can be recruited from outside. In the large technology-oriented firms, an R&D planning office has often been established at the corporate policy level. This will have corporation-wide responsibility for evaluating R&D choices, monitoring the quality and progress of the R&D program, and relating the R&D agenda to company objectives of market position, competitiveness, and profitability.[3]

The senior research managers and the company's research operation as a whole have dual functions which are fundamentally in conflict and which must be judiciously balanced if the influence of these managers on corporate policy is to be effective. Research managers must collaborate wholeheartedly with all other elements in the company, sometimes at the expense of cherished desires, to attain the agreed-upon goals of growth and profitability. At the same time, they must continuously disturb the corporate equilibrium by expressing dissatisfaction with things as they are and emphasizing how they can be better. They must play at the same time the part of team-players and gadflies.

THE R&D PROGRAM AND BUDGET

The formulation of a company's R&D program and the preparation of research budgets for the corporation and its major divisions must be an ongoing activity, but in reality the most critical and difficult decisions are made at that time of year when the company projects its operating budget and its profit generation and cash flow with considerable accuracy for the year to come and with somewhat less accuracy for several years beyond (see Table 4-1).

After the general level of funding and the broad strategies have been determined, the department heads and middle managers below the most senior research executives assume a vital part in formulating the actual research program which is to be carried out.

The bulk of expenditures probably centers on projects which carry over from earlier years with perhaps some modification. Much defensive research, devoted to continuing improvement of existing products and processes over a broad span of years, is fairly easy to justify to corporate and operating management. The costs and pay-out can be predicted with reasonable accuracy from past experience.

Funds which become available from the termination of projects which have either failed or been successfully transferred from research to the operating groups in the company, plus any growth in funds which the corporate management may be willing to spend on research, create the opportunity to undertake a certain number of new projects. Any effective R&D organization has a backlog of proposals for entirely new projects or substantial modifications of older ones. This project list is much greater than the company can possibly support. Not only are new project proposals submitted by both senior and junior engineers and scientists in the research organization itself, but many emanate from marketing and production groups who, from their vantage point, perceive both problems to be solved and opportunities to be exploited.

PROJECT SELECTION

Each corporation, and indeed each major research group in the corporation, develops both general philosophy (perhaps expressed in written documents and perhaps simply based upon past practice and not codified) and a set of procedures for evaluating and selecting the projects which make up the research program.

American literature on R&D management contains a great deal of discussion about how to select R&D projects. Such procedures for selection include both scoring techniques and quantification techniques for ranking and selecting projects. These techniques in themselves are not a solution to the selection or prioritization process for R&D projects. Some quantitative techniques can be useful even at the earliest stage such as numerical weightings assigned to the various factors considered in assessing the merits of a proposal or even, assuming the project to be successful, a pro forma profit and loss or cash flow projection for future years. But, although such quantitative methods have some utility, qualitative and subjective judgments based upon the past experience of the industry, the company, and the research managers, along with a knowledge of current trends in the business and in the technological area in question, are more important in appraising new project proposals.

Among the major questions considered in accepting or rejecting a proposal for a new R&D project or even a major modification of an old one are:

> Does the new product, or the new process which might substantially reduce the cost of an existing product, serve a well-defined market need?
>
> If the research is successful, can it be exploited expeditiously by the manufacturing and marketing arms of the company? The importance of compatibility of the prospective new technology with the company's current operations and its background experience can hardly be overestimated. If a new product can be produced with existing equipment, not only will large new capital investment be unnecessary but prolonged training of a new labor force can probably be avoided. If the product can be sold by the existing marketing organization to customers who already buy the present products of the company, it is unnecessary to employ and train entirely new marketing people and to establish relations with customers who know little about the company.
>
> Does the company have the financial capabilily not only to make new capital investments in manufacturing facilities but also to introduce the product successfully to present

customers and to new customers? Can the company provide the technical services necessary to show a customer how to use its new products and processes and to solve the problems which the customer will inevitably encounter in so doing?

What are the prospects for proprietary protection either by obtaining strong patents or building up a comprehensive body of confidential technical information which cannot readily be duplicated by a competitor?

What are the competitive threats from other companies in the same industry or in other industries and from technologies which may be quite different but which can meet the market need?

What current or prospective government regulations can either greatly increase the cost of successfully completing the development or adversely influence the ultimate use of the technology by the customers?

A few comments about the relative importance of these factors are in order. Until the decade of the 1960s many R&D managers worked with a rather naive model of the innovation process: capable professional engineers and scientists focused on interesting new areas of technology and--with relatively little input from commercial sources--embarked on programs of small-scale research usually labeled "basic," "exploratory," or "pioneering." Success in this stage would result in large-scale "applied laboratory" development. The technology would be further proved out in pilot plants and then could be expected to find rapid exploitation by the manufacturing and marketing branches of the company whose customers could be readily persuaded to purchase the products of such clearly superior technical developments.

Many students of the innovation process, prominent among them Donald Marquis at MIT's Sloan School, began to question this simple model. Their broad investigation into actual experience in past technological innovation pointed strongly to clearly perceived need in the marketplace as the driving force for successful innovation. Marquis and his co-workers have estimated that "need-pull," where the innovators saw the market need and created the technology, or assembled its elements from existing sources in order to fill the need is more important than "technology-push," where a new technology is created by pioneering research efforts and then finds utility in the economy, by a factor of four to one.[4] Moreover, scientific and engineering research is now understood to be only one factor in the overall innovation process. One study found that only 17 percent of railroad innovations, 2.7 percent of housing innovations, and 44 percent of computer innovations were based directly on some identifiable piece of R&D.[5]

There is still fairly vigorous dissent about the tendency to downgrade the importance of highly novel technology in innovations of major significance in the economy. A leading research authority from the academic community has recently argued:

> In all experience, users and needs follow rather than precede innovation. No one is born needing the telephone, and society before 1876 got along very well without it. Once invented and promoted, the telephone became addictive to individuals and nations. A user community grew up. So it was with railroads, automobiles, and airplanes. There was no widespread economic impact until a long course of technological endeavor had demonstrated an addictive capability. With that came economic success.[6]

Tribus has observed that this debate is not particularly productive.

It is often claimed that innovation should proceed in response to a "market pull" rather than a "technological push." The idea is that first market research should be done to identify needs and then research should be undertaken to develop the technology. This dichotomy is not very instructive for it is the combination of "pull" and "push" that determines the course of innovation in most instances. If one examines major contributions, such as the transistor, the instant photograph, the float method for making plate glass, frozen orange juice, the basic oxygen process, the photocopier, etc., one almost invariably finds an entrepreneur who knew full well what market was to be served and what it took to serve it. For example, tape-recorded interviews with Chester Carlson, the inventor of xerography, show that he understood the weaknesses of the photostatic copiers then in use (based upon silver halide photography) and was dissatisfied with the service he obtained from them (he was a patent attorney). He set out to design a replacement. It is doubtful, however, that any market studies made at the time would have identified this as a "need" since the amount of photocopying being done at that time was not very great and the market would have not looked attractive. It was the inventor's idea to respond to a need he perceived. There are very few instances available in which someone studied the marketplace, identified the need and then placed a requisition upon the research community to come up with a solution. The process is iterative--technological opportunities and market needs must be studied simultaneously and each adjusted to advances in understanding the other.[7]

As something of a corollary to our increasing appreciation of the driving force of a perceived market need to creating technology which will ultimately be utilized, there is increasing recognition by business strategists and financial planners of the importance of a company's market share in determining the profitability of a particular product or product line. Thus R&D programs which can promise to protect or increase the market share of the company's products may find more ready acceptance than programs aimed at introducing products entirely new to the company, particularly if such new products must compete for market share with the well-established products of competitors.

For these and other reasons the hurdles to be overcome in justifying an R&D project aimed at taking the company into entirely new fields are increasingly high, particularly since recent experience has shown the failure rate on such projects to be large.

A closely related area of macroeconomic factors involves the characteristics of the market into which the innovation would have to be sold. The prospective market must have sufficient size and coherence to represent an opportunity which is large enough to give promise of recovering the necessary investment in research and development and production capacity, and then to generate a profit from the total undertaking. For example, the health care delivery industry is highly fragmented geographically, as is the educational industry, with public school systems scattered all over the United States--each operating with great autonomy. These markets are difficult targets for innovation. Moreover, if the firms in the target market are in a poor position financially, they represent relatively unattractive markets because they simply lack the resources to purchase technically-advanced products. Thus prospective suppliers have little incentive to attempt innovation.

Another important factor one might label "sensitivity to technology": how much difference can advanced technology make in the growth and the profitability of a given market? Here, two considerations are dominant. The first is the degree of sophistication of the potential customer. The customer must be able to perceive the consequences of an innovation and must be convinced of its value to him. If this is not true, it is unlikely that he can be regarded as an attractive customer. Frequently, the first critical factor in making an innovation succeed is the ability to design the product so that the difference represented by the innovation can be perceived by the customer. In addition, a significant educational effort may be required to convince him of the value of the difference the innovation creates. The second aspect of the sensitivity to technology, of course, is the inherent technical opportunity. Some fields have seen remarkable technical progress in the period since World War II. Consequently, a high rate of innovation has been incurred in those industries.[8]

The prospects for substantial and profitable international sales are increasingly taken into account in selecting projects and in following them to completion. Many leading firms derive as much as half their profits from overseas sales. Furthermore, if the market for a product is built up by exportation from the United States, attractive opportunities for capital investment for manufacturing the product in other countries are likely. Overseas markets for products of a high technological content have been extremely important in such fields as computers and electronic devices and pharmaceuticals and agricultural chemicals.

That small incremental improvements are significant in determining manufacturing economics is increasingly recognized. Conventional research contributes little to some such improvements. Instead the improved skills of the work force may be the more important factor.

In a study of DuPont rayon plants, Samuel Hollander found that technical change accounted for some 35 to 100 percent of the total net reduction in unit factory costs at those factories which he studied; he further found that "minor" technical changes accounted for over two-thirds of the unit-cost reductions attributable to technical changes. These were not the "major" changes dependent upon formal research and development mechanisms; instead, they were implemented by plant personnel intimately linked with operations. When put together, these minor technical changes added up to a fairly large-scale technical advance which produced major economic savings. Fritz Machlup has also emphasized the economic importance of a collection of such minor improvements in technology.[9]

Furthermore, the fact that these process improvements were made on the "factory floor," as it were, and not in the R&D laboratories, indicates the importance of contact with the actual operating phases of production as a stimulus to innovation. R&D labs may make the major breakthroughs, but the minor incremental changes--which can add up to major savings in labor, materials, energy, and the like--more frequently come from those who are intimately connected with the production process itself.

However, the data from Hollander also suggest a "saturation effect," for without some preceding "major change," the potential stream of minor changes will be exhausted. "Minor" changes can be expected for a considerable time--some 10 to 15 years in the DuPont data--after the occurrence of the "major" change. Such major changes come largely through R&D efforts; to the innovation improvements in processes occasioned by the R&D efforts, the plant personnel add "minor" improvements.

The sum of the effects of such incremental contributions has been designated the "experience curve." Bodde has pointed out that in some industries conventional R&D is indeed important;

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Innovations and improvements in manufacturing can be a significant force behind the experience curve. This is particularly true of industries in which worker learning is a relatively minor source of economies. In such a case, process innovations and/or substitution effects become much more important sources of cost reductions.

The electronic semiconductor industry presents an excellent example of process change. In this business most of the experience effect stems from improved production technology itself.

To bring about this sort of technological change the semiconductor industry devotes a large fraction of its R&D to process improvements. Technical personnel study the production system and experiment with potential improvements. Top management constantly devotes its attention to realizing experience curve economics. As a result strong experience curves of 70 to 80 percent are common in this industry despite the absence of a powerful worker-learning effect.[10] *

As an illustration of the increasing awareness of the very real effects of the experience curve phenomenon, it has recently been argued that technology for production of synthetic liquid fuels from coal would be more rapidly advanced by building a demonstration plant of commercial size using the best technology now available and relying on the experience curve to achieve manufacturing econ-

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*The unit cost after doubling the units of production is expressed as the percent of cost before doubling. For a 70 percent curve, the cost of the fourth unit is 70 percent of the second; the eighth is 70 percent of the cost of the fourth; the 100th is 70 percent of the 50th.

omies, as opposed to prolonging programs of small-scale experimentation which seek an optimal conversion technology.[11]

The important contributions of the research professionals who bring about these incremental experience curve effects should not be denigrated. Successful companies assign some of their most productive research people to such programs. It might also be observed that much of the truly basic research carried out by a company may be concerned with well-established products and processes. Detailed investigation of a reaction mechanism or of the fundamental properties of a catalyst may produce information of great value when billions of units of a particular product are turned out each year. Studies of the mode of action of a drug may suggest new areas of therapy in which it can be useful.*

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*Not more than a handful of companies have organized programs of basic research in the sense of investigating scientific phenomena for the sake of adding to our store of knowledge. The surveys carried out by NSF elicit data on company research spending on projects "having specific commercial objectives although such investigations may be in fields of present or potential interest to the company." Obviously judgment must be exercised in proper labeling, e.g., projects of a highly exploratory or pioneering nature which may probe uncharted areas of science but which will obviously have real commercial significance if successful, and projects such as those mentioned above, where fundamental investigations are carried out and published, but which relate closely to a firm's established business activities. According to the available information, industry accounts for 16 percent of basic research spending and provides for 80 percent of this with its funds. The chemical and pharmaceutical industries are the leading supporters of basic research, followed by electrical equipment.

For these reasons, the bulk of a company's R&D program and the major expenditure in its budget are concerned with its established businesses and comprise, for the most part, projects of an evolutionary nature. Almost every company, however, makes some effort to compensate by devoting some of its resources to pioneering and exploratory efforts in new technical fields of possible long-term interest. Many large companies maintain a corporate research group for such activities (see "Organization of R&D"). Certain companies have a policy of allocating perhaps 10 to 20 percent of R&D expenditures to be spent at the discretion of the experienced R&D managers on exploratory projects. Some R&D managements fund exploratory research projects in fields of potential interest at universities or research institutes which have established expertise in a particular technology. In this way the significance of the new technology to the company can be evaluated to some degree before the company makes a substantial commitment of new staff and facilities for an in-house program.

On the responsibilities of industrial research people in seeking opportunities for truly major advances, O.B. Butler of the Procter and Gamble Company has written:

> Perhaps the single most important thing we expect from our research and development community is that they directly and personally think about, dialogue with, know, understand, and hopefully empathize with the ultimate consumers or potential consumers of our products. We have close and continuing contact and dialogue between our brand managers and our product development organization, but we insist that communication between research and development on one hand and consumers on

the other hand not go through a middleman. The reason is simple. Any middleman standing between the inventor and the ultimate consumer is likely to tell the inventor what the consumer says he or she wants, and this is seldom the basis for the great innovation. As consumers, we seldom know what we want. It would never have occurred to me to ask someone to make a razor with two blades instead of one, but now that I have had a chance to use one, I would never go back to the old system. Consumers tend to think in terms of very minor improvements--a kind of polishing, if you will--of the products they are accustomed to using. The research and development operation which is tailored to what consumers think they want, particularly when this want is transmitted through a third party, is almost bound to spend its life working on minor improvements that have little economic value when realized, because too many others have made the same improvement at the same time.

We expect our development people to talk with brand managers, with market research people, and with the consumer directly. We expect them to search for needs or desires that the consumer perhaps has not yet perceived, but that the consumer will regard as important, once recognized. The identification of such a need may come from anywhere, from any conversation with anyone, from something one might read, or even occasionally from research carefully planned to elicit this kind of information. The important thing is that we understand this is what we are searching for, and that we recognize that big idea whenever and wherever it appears. This kind of research and development program is aimed not at giving consumers what

they want, but rather at giving consumers
what they will want or should want.[12]

The typical R&D budget of the corporation is arrived at by a process of successive approximations, "cut and try" procedures, and bargaining between research people and others in the company who must ultimately approve the expenditures. The senior research managers are crucial in this process, interpreting to the financial decision makers the importance of various technological thrusts, competitive threats which must be countered, and the penalties for missing certain opportunities. Conversely, they must communicate to the R&D people the constraints imposed by the necessity to generate current profits and the need for reasonable prudence about entering too many new fields which may indeed be challenging, but which are outside the firm's demonstrated competence, and thus embarking on too many long-term programs whose pay-off can be foreseen only in the dim and distant future.

In an R&D budget the most important component is the cost of personnel, and budget increases approved determine the number of new people who can be recruited for the R&D staff. Wages and salaries of R&D personnel, plus associated fringe benefits, account for one-half of industrial research spending (professional salaries are about one-third of the total), materials and supplies 16 percent, and other costs such as taxes and depreciation 34 percent.[13]

Several factors affect the relative importance of these cost components. Development, for example, often requires the construction of a pilot plant, which raises the relative importance of materials, supplies and capital costs. Basic research and applied research in its early stages typically do not entail such outlays. Employee compensation depends not only on the salary levels in the industry, but also on the occupational or professional mix of the work force engaged in the

R&D effort. If other factors remain the same, the greater the proportion of professional employees (scientists and engineers) to all R&D employment, the greater the relative importance of salaries and wages. In general, one would expect the professional component to be relatively large in basic research or in applied research as the new knowledge being sought and used moves close to the scientific frontier.[14]

MONITORING AND EVALUATION OF ON-GOING RESEARCH

From the first day when dollars are spent on a project in a corporation, the project is subjected to evaluation and monitoring by individuals and groups within and without the R&D organization itself. Even projects of the most exploratory nature are looked over carefully from time to time to see if the optimistic predictions of technical achievement which have probably been made by its sponsors are indeed taking place even after reasonable allowance for the usual overruns in time and cost.

Each company, and indeed each division of a large company, develops its own preferred methods for project evaluation, some quite formal and some informal. We discussed government evaluation techniques in Chapter 3. Here we discuss those in industry. Various groups, e.g., process engineering sections of the research organization on the one hand and the company's marketing department on the other, often prepare separate evaluations using techniques and criteria suitable to their functions. In large corporations the Research Planning Groups are charged with project evaluation (Figure 5-2).

Obviously, complex and highly quantitative formulas for evaluation are necessary and appropriate for projects in an advanced stage of development, for example, at the stage of large pilot plant operation or the stage of test marketing of com-

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mercial prototypes, and similarly inappropriate for the early stages of basic or exploratory research. The stages in between are critically important. Here there is continuing controversy about the utility of sophisticated quantitative evaluation methods. Traditionally, professional researchers tend to suspect quantitative evaluation techniques when many uncertainties must still be faced in the evolution of a project on the following grounds:

> Important qualitative and subjective factors are too often ignored.
>
> To those unfamiliar with the research process quantitative techniques give a false impression of accuracy at a stage when many of the inputs are no more than educated guesses: to use the computer term, "garbage in--garbage out." It is notorious in new product development that the predicted selling price per unit often carries the most weight in a product evaluation and is often the factor most difficult to project. Those trained in scientific disciplines are inherently fearful of conveying the impression of greater precision in the numbers they present to outside groups than can possibly be justified.
>
> Reliance on these methods "puts R&D in a straight jacket." Discounted cash flow evaluations tend to make all long-range projects look poor in comparison to marginal improvements of current technology. Yet it usually takes five to 10 years to create and begin to exploit truly new technical achievements. Moreover, proliferation of new uses for a product, often unforeseen in the early stages of research, has been important in the success of many major developments.

On the other hand, the great advantages in even roughly quantitative evaluations are that their use forces diverse individuals and groups to focus on certain critical measurements so that disagreements about their value and their significance can be expressed in explicit terms. Furthermore, such quantitative techniques readily lend themselves to a sensitivity analysis showing rather clearly which remaining uncertainties are most important in determining the likely success of the project and thus where the corporation's resources should be concentrated to deal with the uncertainties.

Tribus remarks in his discussion of decision analysis and its use in R&D:

> The important contribution of decision analysis to this process is that it enables each person who presents information to introduce the extent of his or her own uncertainty in a quantitative way. If this is not done the person presenting the information is faced with a very difficult task: appearing before the top management to present neither more nor less than is truly known without appearing to be evasive.[15]

It is vital that the performer of R&D, even at the most junior level, become entirely familiar with the systems used to monitor and evaluate the projects on which he is working and thus become a full participant in the evaluation process. In recent years this has been made easier by the widespread use of computers which have been programmed to carry out complex quantitative evaluations and to which R&D personnel have ready access.

Much has been published about evaluation techniques used in American industry. Almost all techniques use discounted cash flow calculations to establish a present value for a given project.

In monitoring important projects, most companies use "Time and Events Schedules" for those where the inputs derive mostly from the research organization itself (Figures 5-3 and 5-4). Critical Path scheduling is widely used when a number of R&D groups are involved and where important inputs from other divisions of the company or from outside the company are expected. Probably only the largest companies regularly use the PERT method, and then only for the most complex programs. Formalized cost-benefit analysis has, as yet, limited use in the typical American company.

Steele has discussed the use of systems approaches in planning and managing R&D. He defines these simply as "A way of trying to deal with all the components of a problem at the same time."[16]

Systems analysis (including cost effectiveness measures) is extremely useful and widely practiced as an approach to resolving problems of resource allocation in which an R&D element is present. The analysis is applied to the larger objectives while the R&D options are weighed as means toward meeting the objectives desired. The decision maker (government or industry) has certain goals and alternative ways to reach them. Systems analysis can help to define the objectives and examine the alternatives from the standpoint of costs, benefits, and effectiveness. R&D resources are a dependent input in relation to many other variables, and in some cases may even be the critical factor in selecting one alternative against others. In this sense, systems analysis is widely practiced in American government and in planning and administering R&D.

The goal of systems analysis is to clarify how parts of a system interact with one another and how these elements can be specified and brought into proper relationship for the optimum attainment of the objectives of the system. More specifically, in order to be successful, systems analysis must accomplish the following tasks:

1. Specify the bounds of the system under

study, i.e., define its limits and its interface with the external universe

2. Identify with acceptable precision the objectives of the system to be designed

3. Develop objective, preferably quantitative, measures of performance for the entire system

4. Identify and specify the components and configurations that are required to make the system operate

5. Specify the relationships and interactions among the various components of the system

6. Establish data on the behavior of individual components and their interactions with the system

The objectives sought under this broader view include:

1. Provide management with as much information as possible to guide and control the overall program

2. Formulate long-range plans and objectives as a framework for integrating individual projects

3. Balance the total program to assure progress along all needed lines, at the same time making the best use of manpower and other resources

4. Develop objectives and plans for individual projects that are consistent with long-range objectives

5. Keep abreast of new ideas, principles, methods, and devices; ensure the best and most timely use of new technology

6. Carry out each operation in the process in the most efficient manner possible, recognizing that the requirements for detail, accuracy and speed depend upon the phase of the process in which one is working

This planning process cannot work unless the necessary hierarchical classification structure has been developed, extensive means of providing inputs on company plans and operating programs throughout the corporation have been developed, and extensive interaction with the key members of the technical staff in reviewing present and prospective programs in the R&D function already exists. Note, however, that this mode of planning operates under one continuing constraint: it takes the economic goals of the corporation as given. Consequently, this mode of planning does not address the critical second role of the R&D function: to effect change, to seek to provide new technological capability that would lead the corporation to adopt new economic goals.

George A. Steiner has accurately pointed out that the importance of systems analysis to business is that it reinforces the understanding of the manager that he is running a business, not sub-systems; it focuses attention on the central role of top management in decision-making; it tells managers that the scientific method can be effective in dealing with poorly structured problems; and it has stimulated the interest of scientists in helping managers to make decisions. The limitations, Steiner notes, are that for large and important problems the analysis inherently is incomplete, measures of benefit frequently are only approximate, and uncertainties about the future limit the application of analysis without much judgment.[17]

Systems analysis and the complex of techniques associated with it were developed for application in a different regime of management. In its most elaborate form it provided the means for undertaking and carrying out programs of a magnitude and complexity that otherwise would have been virtually impossible without unacceptable demands for resources. In its more popular guise, systems analysis frequently connotes a level of rigor and of quantification that is unattainable in the management of R&D. Nevertheless, the conceptual framework and cognitive set required for systems analysis have a close affinity with the scientific method and logical approach that are basic to R&D. Consequently, with suitable modifications in approach, reductions in the requirements for quantification, and limitations on level of generality to which it can be applied, it is being used more widely by R&D managers--frequently without explicit recognition of the intellectual debt to systems analysis, but rather simply because the techniques give promise of improving management effectiveness.

The deep concern of technical managers is that the technique is often applied indiscriminately with consequent harm to R&D. For the most difficult general questions the approach has very limited value, a constraint that may be intrinsic in cognitive processes.[18]

Formal methods for evaluating the results of research and development have their place at a variety of levels of planning. As a generalization, these formal methods rarely constitute the primary mechanism for resource allocation decisions. The further one goes toward the fundamental research end of the R&D spectrum, the less effective these formal methods have proved and the more they represent simply a formalization of the process whereby subjective judgments are made.[19]

Many factors shape a company's decision about whether to terminate, continue, expand, or totally redirect a given research project, large or small. Factors from the internal and external environments must be evaluated. Changes in the initial estimates of manufacturing costs are clearly important. Unfortunately, experience has shown that the cost of completing the research itself and the time required to carry it to commercialization seem always to escalate. In most instances, however, the most critical factor is continuing assurance of the receptivity of the marketplace to the results of the new technology, whether it be a totally new product or a reduced cost for an old or a modified product. It is in this area that disputes between the advocates of the project and the skeptics are likely to be sharpest.

A factor which must be carefully assessed is the present or predicted action of competitors in response to the threat posed to them by introduction of new technology. Possible strategies for countering these actions must be devised.

Sometimes other technology under development in the company itself is sufficiently attractive to force termination of a project. On the other hand, such technology can be most useful at speeding the project to completion. In the Bell System's development of its Electronic Switching System the recognition at a critical stage that a new random access memory device having large capacity, as well as high speed and low cost, could be created provided justification for proceeding as rapidly as possible in the effort.[20] On occasion, a company finds it advantageous either to license important technology which can supplement its particular effort or, in other instances, to buy a company whose technology, geographic position, or marketing strengths can make commercial exploitation of its particular research development much faster and easier.

Certainly, there is a high attrition rate among research projects in the typical company, usually before they enter the stage of advanced development when the rate of spending accelerates sharply. Those familiar with centrally planned economies sometimes express the opinion that private sector research in the U.S. must suffer some loss of efficiency because of duplication of effort by competing firms. Although few quantitative studies are available, it is probably true that more corporations have engaged in research in certain glamorous and exciting fields such as laser development or the application of anionic polymerization techniques to plastics and elastomer manufacture than could possibly be expected to commercialize their development profitably. This may now also be true of many companies researching the technology for solar energy. In reality, however, many checks and balances come into play. Knowledge of the scope and magnitude of competitive efforts has been cited as an important input in project evaluation. Information about such efforts is obtained quite legitimately by the publication of patent applications in non-examination countries where they become available very quickly and from feedback by customers who are testing new products offered by competitors. In addition, some firms, after having established what they believe to be a strong technical position in a field, publicize their accomplishments instead of keeping them confidential in order to warn off potential competitors. These, and other means of communication, make reasonably sophisticated managements well aware of the difficulties they may encounter in continuing to develop and trying to exploit their particular technical approaches. Although this overall process may sound inefficient, American business and American research managers are firmly convinced that the net result is beneficial to the economy and the society. Time and again, a company which apparently has limited capabilities in a given area of technology or business, by bringing fresh technical insights and innovative management methods to bear, is successful in a new business and introduces healthy competition to older, established companies.

UTILIZATION OF SUCCESSFUL R&D IN THE CORPORATION

Research and development by themselves do not result in the development of an innovation; to complete the process the R&D must be applied or implemented (Figure 5-2). The process is complete when an R&D result has been translated into a new or improved product, process, or service and successfully introduced into the marketplace or some other external environment.

The steps that link R&D with the operating units of the private firms are crucial elements of the innovation process. This is often an area fraught with stumbling blocks, where imaginative ideas and ingenious devices and products fail to enter production and hence application. This explains, in part, why so many patents are never exploited and put into actual production.

In a survey, Edwin Mansfield found that R&D executives of 20 major chemical, drug and electronics companies in the United States estimated that the success rate of innovation would be boosted by 50 percent if R&D results were fully and properly exploited by the manufacturing and marketing people of their companies. Interestingly enough, the non-R&D executives of those same companies felt the percentage would have been even higher.

There are many reasons why so many innovations fail to pass from completed R&D to application. One is that the investment required to bring an innovation to the marketplace is usually five to 20 times the investment in R&D. In his sampling of chemical, mechanical, and electronics firms, Mansfield found that 29.1 percent of the total innovation expenditures concerned prototype or pilot plants and 36.9 percent involved manufacturing start-up costs. In the industries surveyed, over 75 percent of the total innovation expenditures occurred during implementation. In other words, the financial stakes are much higher at this point, so the decision to implement involves more weighty factors--at least in financial terms.

Another reason is that more variables are involved in making the crucial decision to move from R&D to implementation, and the information about these variables tends to be "softer" than the scientific and technical data utilized in the R&D process. Here is where managerial acumen counts the most to match the demands of the marketplace, the capabilities of the firm, and the scientific and technical performance promised by the innovation.[21]

Generally speaking, success in the introduction of a new technology or a new technical capability has to be earned through competition with old technology. Innovation rarely moves into a social, economic, or technical vacuum. This success is typically created by people who strive--sometimes vigorously and insistently--for change. Consequently, conflict is almost inevitable between those advocating the new and those protecting the conventional technology. When innovation is ineffective, the problem may result from inadequate strength in those seeking to innovate.

It is well known that innovation frequently occurs from the outside. The innovation "invades" the territory of a presently used technology. Consequently, one principle for promoting innovation in a given enterprise is this: do not expect the advocates of a present technology simultaneously to nurture a new, competing technology. The organizational structure must normally be arranged so that those charged with seeking to achieve innovation are not at the same time responsible for effective application of the present conventional technology. The innovative effort usually needs a separate, autonomous sponsorship. This is one of the reasons for creating a research and development activity at the corporate level, independent of the technical work associated with individual operating units of the enterprise. Operating units typically devote most of their attention to the

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pursuit and practice of present state-of-the-art technology, and they sometimes tend to resist the introduction of new technology because to them it is disruptive and threatening.[22]

Jack Morton of Bell Laboratories has devised what has come to be known as the "barriers and bonds" theory. This theory recognizes that the movement of a technological innovation along the chain from basic research to applied research and on into application typically involves the transfer of the technology from one organizational component to another charged with work at the next stage in the process. It frequently also involves physical movement of the technological innovation from one geographic location to another. Morton's research supports the insight that when both an organizational barrier and a geographical barrier exist simultaneously it is exceedingly unlikely that effective technology transfer will occur. This insight led Morton to conclude that care should be taken in organizing technical work to insure that when there is a geographical barrier there is explicit provision for an organizational bond. In other words, when the work moves physically from one location to another it should occur under a common organizational "umbrella." Without this organizational bonding the transition will almost certainly not occur. Where work is to be moved from one organizational group to another it is advantageous if the groups are set up to be geographically contiguous, otherwise communications required to accomplish the transition will not occur.[23]

There are always strong elements of "selling" in overcoming the barriers to commercialization of any promising technical development in a company. Even in a company as well integrated as American Telephone and Telegraph, with a long history of reliance on new technology, it was the operating groups which were responsible for the decision to adopt the new electronic switching system.[24]

In the typical corporation, when the senior research management recommends that some new development be moved to an operating group for commercial exploitation an array of proponents and opponents emerges. The advocates are not all necessarily from the R&D organization nor the skeptics from the operating groups. The role of senior corporate management is often critical. Various studies of successful industrial research projects have emphasized the importance of "the advocate" who pushes the project with single-minded zeal and "the high-level sponsor" who takes the project under his wing. In a small concern, this sponsor is frequently the president himself.

Many problems not clearly foreseen while the research was underway surface at the implementation stage. Perhaps there are certain hazards in transporting the product or a feed-stock. A definite production site must be identified unless old facilities can be suitably modified. Skilled labor may not be available. Effluents may not be easily disposable. Costs will probably tend to rise above those projected in the R&D phase. In companies of small to medium size, the availability of financing, in turn dependent upon the current state of the securities markets, must be considered. The most recent government regulations affecting the manufacture and use of the product must be analyzed in detail.

For the most part, however, the market acceptance of the result of the new technology is most often the key factor. Many a project has moved to commercialization only when an important customer --sometimes, as we have seen, the federal government--is willing to sign firm contracts for purchase of all or part of the output of the first facility which incorporates the new technology.

To cope with problems transfering new technology to profitable commercial business operations, a number of American companies have sought innovative management techniques. Some have set up New Business Groups or Task Forces which are staffed with people experienced in research, manufacturing, and marketing. These groups plan and coordinate exploitation of the new development.

To an increasing extent, companies are making use of the project manager or venture manager system in which an individual is designated to plan, coordinate, and monitor an overall technical program in which various elements are carried out by different groups in the company, supplemented perhaps by outside groups. This project manager functions usually in a staff capacity and is assigned certain funds and authority to manage his program efficiently. If the project is successful, and if it is in a new business field, the R&D may result in a "new venture" division or a new subsidiary company which may well be headed by the successful project manager. The opportunity for promotion to such management posts is a powerful incentive for good performance during the R&D phase of the venture.[25] The new business group or the project manager should report at a high level in the organization so that he can readily bring problems and opportunities to the attention of those in a position to act quickly.

The 3M Company, in particular, has gone a step beyond the conventional project manager method and devised a system in which a manager is designated to take charge of a project while it is still in the development stage with almost full responsibility for seeing it through to successful commercialization. This person becomes, in effect, a technical entrepreneur within the company. The usual expectation is that he will become the general manager of the new business if it becomes a profitable enterprise. A key to the success of such a system over the years is that, if failure occurs because of factors beyond the manager's control, his future in the company will not be seriously jeopardized.

Other management techniques include giving a top executive multi-functional line authority and providing the research group itself with special funds which permit it to demonstrate successful use of the new technology in cooperative programs with potential customers. Needless to say, many companies have established committees to deal with the problems inherent in the transition of research to commercialization. But it must be admitted that few committees can operate effectively when a clear-cut decision involving high risks must be made.[26]

Obviously, a firm will have many options about how to exploit a clearly promising technological development. The possibility of licensing to other companies is always present. Although broad generalization is difficult, it is fair to say that most companies wish to commercialize their research themselves before licensing to others. Not only does the company thus establish a solid lead over its licensee, who will most likely become its competitor, but it has greatly enhanced the value of the particular development, which will be reflected in advance payments and royalty fees. Moreover, having its own operating experience in eliminating start-up problems means that fewer demands will be made upon its staff in helping the licensee enter production.

Under unusual circumstances, the company may decide to license others before it uses the technology itself. In this case, it may well seek a foreign licensee who may not compete so strongly in the U.S. markets. (Much technology is developed to use products manufactured by the company. Of course, this will almost always be made available to customers on reasonable terms and conditions.)

The sale of an entire development to another firm is mostly regarded as a last resort and usually constitutes an admission that the company has failed in adequately planning its research effort. A large company which has concluded that the business opportunity presented by a new technology is too small to command its resources and management talents may sell the entire development to a small company.

General Electric Company has set up programs under which it permits those who have been heavily involved in such projects to leave the company and set up their own organization to commercialize the technology. It even supplies venture capital to the new enterprise in return for a share in the ownership.[27]

MEASURING THE SUCCESS OF INDUSTRIAL RESEARCH AND INDUSTRIAL RESEARCH ORGANIZATIONS

From time to time it is appropriate, and indeed, necessary, for R&D management and senior corporate management to evaluate the performance of its research operations to determine whether they are making a satisfactory contribution to attaining the goals of the company. The action resulting from these evaluations might be an increase or decrease in funds allocated to research as a whole or to certain major elements in the research effort, or it might be a decision to pioneer in new fields because of past successes, or even to change the key managers responsible for the research planning and execution. R.E. Gee has summed up the inevitable problems in research evaluation:

> R&D _must_ be evaluated because:
>
> 1. R&D is becoming more and more costly; it is an important financial risk that is necessary because of increasing competitive pressure.
>
> 2. Management wants to compare proposed research expenditures with other proposed uses for a limited resource.
>
> 3. Management wants to know how effectively R&D is using allotted resources. Without evaluation, some R&D programs could go on consuming resources indefinitely.

But R&D can't be evaluated because:

1. It is impossible to know which part of the profits or losses from a new development should be credited to R&D since much of the responsibility lies with marketing and manufacturing.

2. Specific R&D objectives related to corporate objectives are often not stated succinctly enough to provide a basis for judging performance.

3. Research objectives are, at best, moving targets.

4. It takes too long to see the results.

5. Data are too uncertain.

6. Creativity may be inhibited by such probing.

7. Such evaluation takes too much time and effort.

8. Some think that only researchers can evaluate research, but that they have a natural bias and may not do the job objectively.

9. Research people are not accustomed to being held accountable.

10. Many benefits of R&D are intangible:

    in technical recruiting and as a training ground for technical employees

    in promoting corporate image and aiding in corporate advertising

    in providing scientific intelligence and consulting

    in technical cross-fertilizing of other

parts of the organization

in evaluating technical threats from competition

in aiding sales to important customers

in backing up applied research with fundamental understanding?[28]

Research, however, is evaluated on the basis of either reasonably objective observations or subjective judgments. It behooves research managers not only to understand thoroughly their company's post-evaluation methods but also to be full participants in formulating and defining them.

Gee and D.W. Collier have proposed a two-phase method of post evaluation which has received considerable study and testing by leading U.S. firms. In the first step, the research group is rated in a quantitative fashion according to its success or failure in meeting objectives agreed upon by the research performers and other groups in the company when the work was initiated. For research carried out in support of existing business, the managers who participate in setting the objectives and judging their attainment come from manufacturing and marketing groups. For research aimed at new business or exploratory research, the outside managers are probably at the corporate level.

In the second step the research operations are rated on their record in generating business opportunities. A business opportunity exists, according to Collier and Gee, if the technology generated by a project has greater potential value in use to the customer than his best present alternative. In these terms, the business opportunity can be quantitatively measured. The appropriate time to measure the business opportunity, furthermore, is when the project is in the process of being transferred from R&D to an operating division in the company which will undertake to commercialize it.[29]

Recently Mobil Corporation reported on its use of post-audit of completed research projects, a technique it has used successfully for over 15 years. Such post-audits are found to offer the following benefits:

> Motivate researchers to select and accomplish money-making objectives
>
> Help identify high business risk objectives, objectives that are unlikely to succeed commercially, even though they succeed technically
>
> Demonstrate research productivity and thus help support the research budget
>
> Identify productive research areas and thus guide shifts in emphasis
>
> Increase confidence in predictive evaluations as a tool for guiding and controlling research

For that particular major petroleum company the post-audits have enabled identification--and avoidance--of certain projects whose success rate has proved to be low:

> Those requiring high capital outlay
>
> Those outside the mainstream of the company's business
>
> Those with poorly defined targets
>
> Those involving small volume products or processes[30]

This is not to suggest that judgmental factors in long-term evaluation are not important. The company president weighing the contribution of his research groups over the period of a decade or more asks:

Have we stayed abreast of our competition in new products and processes?

Are those manufacturing costs of major products which are affected by technology as low as any other company's?

Are we continuously aware of new technical developments outside the company which may be significant for the growth of our business?

Is the research organization recruiting and training sufficient numbers of competent young people who will be resources for the future not only in research but in manufacturing, marketing, and finance?

Thus a mix of evaluation techniques must be brought to bear for useful post-evaluation of both the research effort and the organizations responsible for it.

ORGANIZATION OF R&D IN THE CORPORATE STRUCTURE

The organization of industrial R&D adheres to three broad patterns. The first is a highly centralized mode typical of homogeneous businesses. These companies typically perform virtually all of the R&D in one central organizational component which reports to the highest levels of management in the corporation.

The second mode is fully decentralized R&D typical of highly diversified businesses, often called conglomerates, many of which were formed by acquisition during the last 15 years. In this mode each individual business within the corporate structure is responsible for its own R&D. In most cases there is a vice president for R&D at the corporate staff level who coordinates R&D among various components.

A third mode involves a combination of centralization. It is typical of highly diversified companies which have a strong element of underlying common technology in many of their businesses. In this mode a vice president for corporate R&D manages a corporate laboratory which is responsible for R&D in new technologies or in technologies which are broadly applied across many components. At the same time the individual businesses within the corporation perform product-oriented R&D associated with their assigned business scope. Typically, the vice president for corporate R&D has some coordinating responsibility for R&D in operations in addition to managing the corporate laboratory.

Within a laboratory two major types of R&D structures can be distinguished:

1. "Phase-dominant," where the R&D activity is structured by process phases--for example, research, development, engineering, and tooling--and within which ideas are generated and submitted.

2. "Project-dominant," where the activity is primarily structured by projects, and within which all the distinctive process phases are carried out under one organization and management.[31]

The project-dominant model leads to a single project coordinator, who organizes the team which performs all the project's work. In the phase-dominant model, there are several organizational administrators, each responsible for his individual portion of the project's activity and for its transfer from one organizational unit to another. The phase-dominant model suggests a hierarchical organization; the project-dominant model suggests a matrix organization.

Integrating the phase-dominant and project-dominant organizations to achieve the types of innovations each best produces causes some problems. One solution is known as a "matrix" organization, in which there is a permanent phase-dominant and disciplinary structure from which elements are pulled out temporarily to form projects or systems teams.[32] Research managers and those responsible for funding research and seeing that its results are utilized also debate the advantages of centralized and decentralized systems. Certain advantages of a centralized system are:

> It is easier to assemble the critical mass necessary to undertake complex programs.
>
> By the same token, research professionals of varying backgrounds and expertise can continually interface with others and provide useful inputs for ongoing projects.
>
> The sharing of certain expensive support facilities such as libraries, instruments, and analytical services is easy and makes possible certain economies.
>
> Some degree of insulation is provided from the day-to-day pressures of the immediate problems of marketing and production operations which might divert those engaged in long-term research from their more important assignments.
>
> It is probably easier for a central research organization to recruit the best young university graduates and, in the early years, provide training in the business philosophy and practices of the company.

The advantages cited for decentralized (sometimes called divisional) research are:

> There is improved communication with manufacturing and marketing personnel, and pressing problems of product or manufactur-

ing improvements are understood and dealt with more expeditiously.

It is easier for R&D personnel to become familiar with both the problems and the technological potentials of customer organizations.

The key people in research tend to develop a stronger sense of identification with the business goals of the company, and many become capable more quickly of moving into responsible positions outside the research organization itself.

The corporate and senior research management continually seek an organizational structure most suitable for the nature and stage of growth of the company's principal businesses, the complexity of the technical challenges it faces, its perception of the relative importance of gradual and evolutionary versus radical technical change in its future, and the personal characteristics and backgrounds of the corporate and divisional managers. A great many companies have adopted the so-called "mixed mode." A relatively small corporate organization devoted mostly to new technological investigations coexists with divisional research organizations supporting the established businesses, with constantly changing interfaces between the organizations. Most progressive managements realize the necessity of organizing and planning both for incremental evolutionary changes and for the possibility of major technical breakthroughs.[33]

The search for an optimal organizational structure in terms of established management principles is probably less important than finding one compatible with the philosophies and personal characteristics of those key individuals who make the major decisions in the company. It is also important that one segment of the R&D staff not be seen by others as sheltered or pampered because it is engaged in longer-term and seemingly more glamorous work.

LABORATORY SIZE AND LOCATION

R&D efficiency as a function of laboratory size has been little studied. Many research facilities of the government and private firms in the United States incorporate several laboratories, each with its assigned mission, in a group which constitutes a research center. Thus, it is necessary to consider both the problem of optimal size of a given laboratory and any restrictions which should be placed on the size of the total research activity carried on at a given location.

Size

It has been estimated (with many provisions) that 30 to 50 professionals is a minimum staff. The minimum services required for the laboratory to carry out its assignments vary according to the specific technical fields and problems in which the researchers are engaged. For example, a small research laboratory may require only a small in-house library for its day-to-day information needs, particularly if it can rely upon larger libraries in the vicinity. On the other hand, much research today requires highly sophisticated instrumentation which, in turn, requires considerable repair and maintenance facilities. Only large research installations can justify, for example, the extensive toxicology laboratories and animal testing facilities required for studies on biologically active substances.

Opinions about the maximum efficient staff size of laboratories and research centers show much more variation. Managers in the chemical industry tend to believe rather strongly that efficiency decreases above a laboratory size of 400 to 600 total personnel, corresponding to around 200 to 300 professionals, whereas those in the electrical and electronics industries see no problems with a laboratory size of 1000 to 2000 total. Several in the latter group feel there is no real practical limit to size. There seems, however, to be general agreement that the range of 100 to 500 professionals makes for efficient R&D operation of a laboratory. At the same time, one should aim for no more than 2000 to 3000 total employees at any one location. The sentiment has often been expressed that laboratories devoted to research of an exploratory or pioneering nature should be smaller, in the range of 100 to 150 professionals, than laboratories concerned with product application and technical service, which can advantageously have professional staffs of 200 to 300.

Factors considered important in determining maximum efficient size of a laboratory are:

> Communication within the laboratory may become a problem with large staffs. Up to about 150 professionals, one can rely on relatively informal means of communication. Larger staffs require that the research management devote considerable attention to devising ways to insure that communication among the professional staff is effective.
>
> Very large research groups are inherently difficult to manage. The senior research officer of one of the most successful American companies commented that a manager should have no more than six to eight people reporting directly to him, which means that as laboratories become larger they require several layers of management. This means that the top level managers lose intimate involvement with, and true understanding of, the ongoing research.
>
> Excessive bureaucracy adversely affects morale of the research staff. One research

director of a company distinguished by its rapid growth observed that the junior research man at the bench should have a high degree of visibility and he will not attain this in a laboratory with more than about 100 professionals.[34]

Location

The question of where a company's major research and development laboratories should best be located has been answered by different companies in different ways depending largely on the nature and stage of development of the company's business activities and the background and history of the company itself. In fact, it is not often that a large company can afford the luxury of building completely new laboratory facilities to house all its R&D effort. Rapidly rising construction costs mitigate against abandoning laboratories in use to construct entirely new ones.

Some laboratories have grown up close to major manufacturing facilities whose support services they can share. These are well situated to carry out heavy pilot plant and demonstration plant programs. Companies also frequently place short-term product improvement and technical service laboratories near concentrations of customer facilities.

Less tangible factors are sometimes influential. Many technical entrepreneurs who founded semiconductor companies were educated in the San Francisco Bay area and constructed their laboratories and production facilities in this region because of the appeal of the climate and the educational and professional associations.

Companies with active merger programs acquire laboratory facilities along with a smaller company and most often leave the laboratory in place to serve the need of the acquired organization, at least for a few years.

Perhaps the strongest tendency in this decade has been to locate research facilities reasonably close to corporate and marketing headquarters to provide the best possible communication and feedback at this important interface. It also seems advantageous to build clusters of laboratories at one site in which people engaged in longer-range research can interact continually with those in divisional laboratories concerned with developing current business lines. This also permits sharing of costly support facilities.

Localized concentrations of R&D laboratories and high-technology businesses, frequently called "research parks," began to build up in the late 1970s and the early 1960s, notably near MIT and Harvard and on the peninsula south of San Francisco near Stanford University. In retrospect, some important characteristics of these concentrations can be seen:

> Such research and production facilities were largely oriented toward the aerospace, computer, and communications industries with heavy emphasis on electronics.
>
> There was close, though informal, affiliation with nearby universities, largely through leading research professors who were founders, major shareholders, or consultants to the company establishing the laboratory of production facility. A professor sometimes participated in the founding of the enterprise and later moved to becoming a full-time official in its operation.
>
> Many of the key employees were people who came from government laboratories or from laboratories of large companies primarily concerned with research or manufacture under government contracts.

> In these instances, the small company would start with one or a very few government contract commitments for research or for the production of some sophisticated item. If the business succeeded after this initial phase, the organization could branch out to find more clients for its support, among either government agencies or major industrial firms.

The trend to build research parks coincided with the general interest on the part of states and cities in attracting "science-based industry." The benefits envisioned included expanding the population of relatively well-educated and well-paid professional engineers and scientists and increasing the proportion of stable, tax-paying companies engaged in R&D or light manufacturing as opposed to heavy industry with its attendant problems of pollution and cyclical employment. Among the advantages supposedly offered by the "research parks" or "industrial parks" devoted to laboratories or the manufacture of high-technology products were:

> They were, in many cases, near one or more major universities where faculty could easily act as technical consultants and where library and other useful facilities would be shared.
>
> Proximity to other laboratories would encourage cross-fertilization of technical ideas and possible sharing of facilities such as machine shops, computer centers, etc.
>
> Professional employees of high caliber could be readily attracted to the area by the generally good living conditions and the opportunity for continuing post-graduate education, which was frequently made available to them at the nearby universities.

A recent survey shows that in early 1974, there were 84 "research parks" in the U.S. and Canada ranging in size from a few acres to over 1000 acres. The number of scientists and engineers employed varied from three to 7000 with an average of about 340. The occupancy rate of the research parks was only about 40%.

By and large, it must be said that the research park movement has been less than outstandingly successful and it is likely that these complexes represented something of a temporary phenomenon. In the 1970s, these concentrations of small laboratories and manufacturing companies have had to cope with a number of adverse trends.

They were, of course, hard hit by the cutbacks in aerospace R&D. The managers of these small enterprises which grew up doing business under contract with the government or with much larger aerospace companies have not adapted well to serving non-government customers either in research or in manufacturing and marketing.

In the current U.S. economy, technological emphasis appears to be shifting to the process industries in the energy and environmental fields. It is noteworthy that these have made little use of research parks in expanding their R&D. Important industries such as chemicals, petroleum, mineral processing, and pharmaceuticals have not tended to place significant numbers of their important laboratories in the research parks or similar complexes. Such companies appear to place greater emphasis on locating their laboratories, for example, near corporate headquarters rather than near universities, since access to university contacts can be made available by other means, including closed circuit television to enable employees to hear lectures.

An intangible, but possibly an important, factor has been recent criticism of university professors for neglecting their university research and teaching to further their business interests in high-technology companies.[35]

THE MOTIVATION OF PROFESSIONAL RESEARCH PERSONNEL IN INDUSTRY

The managements of successful companies generally recognize that the skills of their professional research people are a valuable--and expensive--resource. Much thought and effort go into motivating R&D people, improving their productivity, and rewarding outstanding performers.

At the private level, the opportunity to accumulate wealth is undoubtedly the largest single incentive available for stimulating innovative activity. The most significant form of this wealth is personal capital, but it also can take the form of higher compensation paid by the company. A management selection and promotion scheme which gives special attention to excellence in performance in innovation is probably even more important.[36]

The R&D professional is sensitive to both tangible and intangible rewards. In addition to adequate current compensation, he is interested in advancement in the company, whether as a manager of substantial groups inside or outside the research organization itself, or as the possessor of greater freedom and resources which enable him to pursue his technical interests and conduct his research as he desires.

Studies show that scientists are concerned not only with the respect of those higher and lower in the corporate hierarchy but very much with the esteem of their professional peers both in the company and outside the company in other firms, universities, and government bodies. Those trained as engineers by and large tend to be most interested in advancement into management slots which make them responsible for the work of others.

To respond to the aspirations of professional research people and to take account of the inherent differences in the supervisory capabilities of individuals, a number of companies have established a Dual Ladder System under which the research professional can advance in compensation and prestige not only by assuming management responsibility but also by attaining greater technical responsibility for important research efforts in his field of demonstrated ability. In such a position, he may or may not have a sizeable number of other research people reporting to him from time to time. It is essential that people in these staff positions not be insulated entirely from the day-to-day pressures of business problems, but encouraged in every way to contribute to the short as well as the long-term interests of the company as a whole.

With regard to compensation, all successful firms pay base salaries to their research professionals comparable to salaries paid to those in equivalent positions in manufacturing, marketing, finance, etc., and scaled to take account of education, experience, managerial rank, and accomplishments. Companies also take account of the salaries paid by similar firms in their industry and in their geographical area. In addition, most companies have bonus plans to reward outstanding contributions, with the compensation paid in cash or in shares of the company's stock. Usually the most senior research managers participate in the incentive compensation plans maintained by almost all companies for their key executives. These vary in structure. Most common, however, are systems under which a certain share of the profits earned by the firm in a given year is distributed to a limited number of top managers according to their level of responsibility and the evaluation of the contributions they have made to the progress of the firm.

It is worth mentioning that many companies pay moderate sums to the inventors whose names appear on patent applications and issued patents. These awards are regarded as an incentive to research people to be "patent conscious." Usually the sums are not large since it is recognized that the people who carried out the work which results in a patent have made only one of the many contributions required for successful innovation.

Most progressive companies look on their R&D organizations as excellent sources of good managers for the future, not only in research but also in many sectors of manufacturing, marketing, and corporate planning in which good technical training and intimate familiarity with the innovative process are solid assets. The R&D organization may well be the major "entry point" for recruitment of university graduates. The training and development of such promising young people is an important assignment of R&D managers.

A factor particularly favorable to innovation in the United States is the high level of mobility of scientific personnel and the low level of institutional and professional barriers to moving within the broad R&D community. Thus it is not unusual to see people appointed to distinguished faculty positions in universities who have spent their entire career in industrial research, nor is the converse rare. The most useful and dynamic professional and technical meetings in the United States tend to draw equally upon investigators from university, government, and industrial laboratories. Students commonly take post-doctoral training in an industrial laboratory before going to a university, or conversely, in a university before going to government or industry laboratories.[37]

The Technical Entrepreneur

Much has been published about the importance of technological entrepreneurs in the American economy and about their backgrounds, personal characteristics, and motivations. A great many start their careers with large organizations, become dissatisfied with what they perceive as a stifling bureaucracy, and wish to strike out on their own. To an increasing extent, however, wise senior managers in established corporations try to nurture these budding entrepreneurs and tolerate the disruption they cause, although they realize a certain number will leave the organization.

Tribus observes that:

> Behind every important technological advance there has been a single person, readily identified as the entrepreneur who had the courage, foresight, and determination to see it through. Any responsible manager of an organization which expects to be creative and innovative should learn how to recognize and develop such people. There are a few guides to their development. The art of fostering technological entrepreneurship is not well developed.
>
> > Recognize that technological entrepreneurs are almost always "trouble makers." They are not content with the way things are. They are consumed with a desire to change things.
> >
> > Recognize that technological entrepreneurs almost always have very strong egos. They may be very egocentric, much to the distaste of many of their colleagues. They have to have strong egos to survive.
> >
> > Recognize that technological entrepreneurs do not always want to carry a program to completion. As soon as the success of the program seems assured, they are apt to want to start over on a

new project. Therefore, several understudies should always be assigned to pick up the task when the original entrepreneur wants to leave it.

Recognize that the technological entrepreneur is usually driven much more by a desire to have his project succeed than he is to obtain personal rewards. In many instances such entrepreneurs will risk their careers for the success of their ideas. It is important, for example, not to try to "buy off" an entrepreneur by giving him a salary increase and an assignment elsewhere, just to avoid turning down his project. He will find a way to keep working on it in the new position.

All would-be technological entrepreneurs are not competent. The good ones learn through a succession of challenging new assignments. It is important they be exposed to the realities of economic evaluation early in their careers. Nothing is more dangerous to the organization and to the person than to have a technologically oriented entrepreneur who seeks aggressively to promote change without understanding what the consequences of that change will be. A wise manager, therefore, looks to the opportunity to broaden the education of those technological entrepreneurs who appear to have the ability to be successful. Among other things this means:

a. Helping teach the person to "sell" an idea internally to the company.

b. Helping the person to learn how to plan a program.

c. Helping with problems of interpersonal relations.[38]

THE ROLES OF LARGE AND SMALL COMPANIES IN INDUSTRIAL INNOVATION

Whether large or small companies contribute more to technological advance in the U.S. is a subject of continuing debate. NSF statistics indicate that more than 60% of R&D in industry is performed by only 31 large companies, whereas only 5% is performed by all firms having less than 1000 employees (Table 5-5). But a study prepared some years ago for DOC (known as the Charpie Report) pointed up the disproportionately large contributions made to the American economy by individual inventors and small companies.[39]

There is however a "threshold" relationship between firm size and innovation. Up to a certain size, innovation increases more than proportionately to the size; then at some crossover point, varying from industry to industry, innovation does not increase proportionately. For example, the threshold for effective R&D is high in electrical equipment, basic chemicals, and drugs. In primary metals, however, beyond a small size R&D expenditures are negatively correlated with firm size.

Large companies have certain obvious advantages in carrying out R&D:

Their financial resources are sufficient not only to conduct lengthy and sophisti-

TABLE 4-5

R&D PERFORMANCE RELATED TO SIZE OF COMPANY: 1976

NUMBER OF EMPLOYEES	PERCENT OF R&D PERFORMANCE	PERCENT OF ALL R&D PERFORMING COMPANIES
less than 1000	5	90
1000-4999	6	6
5000-9999	6	2
10,000 - 24,999	11	1
25,000 or more	72	1

cated experimental programs but also to exploit the results. Their reputation in the money markets makes finding financing to fund a new venture easy.

Their cash flows from established operations are sufficient to cover years of losses that are likely in a new business begun as a result of successful research.

Their large staffs bring together a wealth of scientific and technical know-how.

They have the management skills to implement commercial strategies to take maximum advantage of new technological opportunities.

But large companies also have certain disadvantages. Simon Kuznets contends that technological innovation may be slowed by the absence of competitive pressures when one large firm dominates an entire industry.[40] Many large corporations lack ability to respond quickly to market opportunities and to take advantage of new technology. Their stake in continuing to use well-proven technologies may be so great that resistance to the introduction of new ones may be insurmountable. Their technical groups may be overspecialized, with poor communication among them. Their decision-making processes may be so time-consuming and rigidly structured that they are plagued with "paralysis by analysis."[41] Furthermore, the government regulations under which some companies operate--especially the public utilities--may inhibit the adventurous entrepreneurship that leads to innovation.[42]

Small entrepreneurial companies generally have limited financial resources and no depth of management. But they can and must take quick advantage of market opportunities. They have no stake in protecting large investments or emotional commitment to old technologies. Their managers, who are also often their owners, can move with single-minded dedication to the immediate task of creating and applying a technology in the shortest possible time.

In general, large and small companies coexist in a healthy symbiotic relationship. Large companies are often major customers for the high-technology products of small ones. Many founders of successful small enterprises received their basic training in large ones.

The practice of a large company's buying a small one to improve marketing, technical and managerial capabilities is sometimes criticized as unfair, but as Tribus points out:

> It may, in fact, be very fair to all parties, including the general public. The small company is good at innovation, but it is not efficient at large scale production and distribution. The large company is poor at innovation, but will be good at manufacture, sales, and distribution when the product is established. The inventors can realize a very good profit from the sale of their company--greater than they would have obtained from the same activity while working in the large company or could realize in a small company of limited resources.
>
> More importantly, it takes a different set of traits to exploit an idea than to develop it. The division of labor between large and small companies represented by production versus innovation may well be an efficient solution for society as a whole.[43]

Small to medium-sized firms can often conduct research more efficiently than the laboratories of large industrial firms. To provide the flexibility necessary for development of innovations, some of the industrial giants--Xerox, General Electric, Exxon--have formed small companies within their larger corporations to encourage advanced technological innovations.

A good example is provided by Exxon Enterprises, Inc., a subsidiary of the world's largest oil company. The purpose of Exxon Enterprises, according to its president, "is to involve the corporation in new technology and in new business opportunities that could have some significance in the 1980s and beyond." Some of the projects fostered by Exxon Enterprises result from ideas generated within the company; when a concept appears commercially viable, a separate company is formed to bring the product of the R&D labs to the market. Other opportunities are presented from outside. Some of the specific products are a high-speed printer, surgery equipment, solar heating panels, and other high-technology products. These new companies are small, high-risk technology firms, and they need the venture capital and the marketing know-how of the parent firm.[44]

TECHNOLOGY INFORMATION FLOWS IN THE CORPORATION

Each organization receives information from the external environment which it translates into its organizational goals, needs, and capabilities. There are three mechanisms by which this information transfer and translation are accomplished:

1. Top management and planning staffs determine corporate policy and strategy, the essence of the firm's values, and match opportunity or need with capability.

2. Technological "gatekeepers" operate as a conduit by which technological information enters the firm.

3. Need (market-demand) and opportunity information may be brought into the firm by "market-need" gatekeepers such as personnel and marketing, technical service, or sales. Thus, at least one formal mechanism (determination of corporate policy and strategy) and two informal agencies (technological and market-need gatekeepers) interact to transfer external data into internal information and then to translate internal information into goals, needs, and capabilities.

Information transfer within the firm is thus significant. This is because the individual researcher is influenced greatly by corporate policy and strategy as set down by top management. Information from management, from technical sources, and from the marketplace focuses the attention of the individual researcher on needs, opportunities, and capabilities. It simultaneously broadens and restricts his perceptual base. Innovative ideas are generated when a reasonable, well-designed match is made of an organizational need or opportunity with a technical capability.[45]

In his publications on technical information flow in the corporation Allen points out that person-to-person contact is significantly more effective than printed information, and that important differences exist between engineers and scientists in their use of information sources.[46]

Awareness of the availability of useful technology from outside the firm which can supplement the firm's own internal developments is a vital aspect of technological flow. Sherman Gee has studied the technology. He concludes that a lower average innovation period is generally associated with the use of multiple technology sources and in particular the use of external sources which can then be reinforced with internal resources. He cautions, however, that this "must be a highly selective process designed to utilize fully in a complementary fashion capabilities and resources already available within the firm."[47]

Recently, many American companies have organized to seek out useful foreign technology. In our economy the degree of aggressiveness demonstrated in adopting foreign technology is a function of the initiative shown by the individual organization. United States international trade is diverse, and this international commerce tends to expose American businessmen to a wide variety of new foreign technology and new equipment. Competitive pressure is the principal driving force for any given firm in determining the rate at which it attempts to adopt new foreign technology. Each firm is seeking an advantage in cost of manufacture and/or in performance of its products. If foreign technology offers the potential of providing an advantage in either of these aspects, there is a strong incentive to adopt it.

The size, sophistication, and general openness of the American market to foreign competitors means that many foreign firms are highly motivated to attempt to sell their products in the American market. This in turn increases the exposure of American companies to competition from foreign equipment and foreign technology and thus provides an additional incentive for American firms to be aware of and adopt foreign technology wherever possible competitive advantages could be obtained.

One barrier to such adoption is simply inertia. Lack of knowledge regarding potentially applicable foreign technology and human tendency to prefer the status quo impede such adoption. Probably a more important barrier is what we call the "NIH" factor, for "not invented here." There is a widespread tendency to regard local or domestic technology as superior by definition because to do otherwise is sometimes interpreted as an affront to nationalistic pride.

The extent of adoption of foreign technology varies widely from field to field. It is less in those areas where the United States has great technical strengths, greater where foreign technology is more advanced than that of the United States, e.g., certain textile machinery and certain pharmaceutical products.

RESEARCH INSTITUTES AND ASSOCIATIONS

It is sometimes advantageous for companies to collaborate in certain types of research, particularly long term and basic research. Thus various research associations with diverse functions and missions have been established. The energy industry is a strong example of collaborative research programs.

In addition to the individual research of various companies, each of the energy industries has an organization which conducts or supports some research as a whole. The type of organization, the size of the effort, and the method of organizing and conducting the research vary among the industries and reflect their institutional character and their historic attitudes toward R&D.

The coal industry, through Bituminous Coal Research, Inc. (BCR), a subsidiary of the National Coal Association (the trade association for the industry), maintains a laboratory to work on industry-wide problems. In addition, individual coal companies can contract with BCR to conduct research on their behalf. The total effort is extremely small compared to that of the other fuel industries with which it competes.

The petroleum industry, through its trade association, the American Petroleum Institute (API), contracts for some specialized, largely basic, research for the industry. The total effort is small compared to that conducted by the individual companies in their own laboratories, which represent one of the largest R&D expenditures by any U.S. industry. Unlike the coal, electric, and gas industries (which maintain laboratories with an industry-wide program) the petroleum industry has no common central laboratory.

The gas industry, through its trade association, the American Gas Association (AGA), conducts a research program at the industry-sponsored Institute of Gas Technology. The Institute acts as a clearing house for information for the industry, conducts training programs, awards advanced degrees (in association with the Illinois Institute of Technology), and carries out a research program for the gas industry. This involves methods for the production of synthetic gas, improved methods of transmission, and new methods of utilizing gas. In addition, the Institute also enters into contracts to conduct research on problems of special interest to individual companies.

Because of the almost total involvement of the government in its development and because it has a single market--the electric utility industry--the nuclear fuel industry has conducted almost no research on its own. The only private investment made in R&D on nuclear fuels has been a small one by the electric utility industries.

Until the last several years, the electric utilities conducted only a limited research program either by individual companies or on an industry-wide basis. Most research was conducted by manufacturers who supplied the plant and equipment purchased by the utilities. The only industry-wide research consisted of a small contract program managed by the Edison Electric Institute, the trade association of the investor-owned segment of the industry. It contracted for work on individual problems common to the industry as a whole.

In 1966 the Electric Research Council (ERC) was formed to coordinate the research efforts of the privately, publicly, and federally-owned segments of the electric industry. The ERC published a major report, Electric Utilities Industry Research and Development Goals Through the Year 2000, which recommended the creation of an Electric Power Research Institute (EPRI) for the electric utility industry. EPRI was created in 1973 and now coordinates industry research efforts and insures that duplication is avoided and promising avenues of research are pursued. It has a professional staff that devises research strategy. Most of the research is conducted through contracts with manufacturers, colleges, universities, and other research organizations.

The electric utility industry has moved rapidly in the past several years to implement an industry-wide R&D program through the creation of EPRI and the commitment to greatly increased funding. The gas industry, through the AGA, has also accelerated its research efforts considerably. The AGA has developed an overall long-term program similar in scope to that developed by the ERC for the electric utility industry that resulted in the creation of EPRI. No action has yet been taken on the report recommendations.[48]

Thus each segment of the vast energy industry has adopted specific mechanisms to serve the needs it perceives by joint research programs. But anti-trust laws administered by the Department of Justice place some severe restraints on collaboration by private companies to the exclusion of other companies in the industry. This subject is much too complex to discuss in any detail; in general, however, collaborative research endeavors must admit all companies in the industry on some equitable basis and at some point they must make the results of the research available to all American industries and the public at large under reasonable terms and conditions.

Also of considerable importance on the American industrial scene are the contract research institutes and corporations. Some, like the Southern Research Institute and SRI International, are non-profit. A few are profit-making corporations, like Arthur D. Little, Inc. These serve both state and federal government bodies, as well as private sector firms, by offering specialized services on a contract basis over a limited term. To a large company they can offer certain technical expertise it may not possess in-house for the solution of a technical problem it encounters. To a small company with limited R&D resources, they can offer integrated research programs in carefully defined areas drawing upon the institute's teams of experts and thus permit the company to investigate technical opportunities on a scale impractical with its own staff and facilities. As an example, such institutes have been particularly active in recent years in pollution control research on behalf of both government and private firms.

The eight major non-for-profit institutes employed about 13,000 people in 1977. Their research volume was $400 million or about 1% of total R&D expenditure in the country. It is probable, however, that their influence in their regions and in certain fields of technological development has been out of proportion to this small dollar expenditures. Battelle Memorial Institute was largely responsible for the early technical development of the Xerox process. Illinois Institute of Technology did pioneering work in magnetic recording. Mellon Institute of Industrial Research has been prominent in petrochemical research and in industrial hygiene. SRI has led in combining marketing and technical research. Its Business Information Program is used by corporations and government bodies throughout the world. In 1977 Midwest Research Institute was selected by DOE to operate a new Solar Research Institute at Golden, Colorado.

THE PATENT SYSTEM

Evaluations of the present patent process and trends in its development provide significant evidence that the process is being continuously refined and improved and that it increasingly fulfulls the Congressional mandate of promoting the progress of the useful arts. The patent system has, of course, enormously stimulated our progress from a small agrarian nation to a great technological and industrial leader. But economists, lawyears, inventors, entrepreneurs, and others continue to debate over the relative merits of the system.[49]

From the beginning, the financial gain of the inventor has been complemented by society's gains in enrichment of knowledge, stimulation of science and technology, and growth of the economy. This was the intent of those who wrote the patent provisions of the Constitution, and the same perception is held by those who govern today.

The report of the President's Commission on the Patent System in 1966 concluded that a successful patent system should meet at least four basic standards.

1. Provide an incentive for new inventions by offering a meaningful reward to the inventor and to his supporter.
2. Promote early public disclosure of new discoveries, so that others may benefit.
3. Encourage other researchers to explore alnternative solutionsto crucial technological problems.
4. Through the process of discovery and disclosure, widen the opportunity for consumers to choose products of higher quality and lower price

The Commission found that the U.S. patent system was basically satisfying these standards.

The right of exclusion for a limited period offered by the patent system encourages the introduction of new products and processes of manufacture into the economy which otherwise might never be obtained, with a resulting higher standard of living for our society. In return for the right of exclusion, the patent laws impose upon the inventor the requirement of disclosure of the invention. The resulting enlargement of technological knowledge facilitates dynamic competition by creating greater opportunities for competitive ventures. Upon expiration of the exclusive period, the invention becomes openly available to the public, who then can practice it without restriction.

In many industries the patent system is a crucial incentive to innovation. Without its protection, high-risk investments would be rare. The patent mechanism reinforces the competitive system by offering shelter to entrepreneurs who are willing to commit resources to innovation. It furnishes part of the rewards for risk-taking. At the same time, the patent system does not always result in the immediate introduction of new products, because the market may not be ready for their introduction or because the improvement may be too marginal to capture sales. A patent may be obtained in many instances for purely defensive reasons, or with the intention of licensing its use rather than developing and marketing the improvement.

The patent system thus serves innovation in various ways, and should be viewed as a flexible, multi-purpose device. Moreover, there are differences among industries; some are patent-oriented while others are not and need not be. The costs of securing and defending a litigated patent are sometimes extremely high, and a contest may drag through the courts for years; therefore, companies are cautious in their judgments as to whether to seek a patent, and they tend to do so only when the decision is of strategic importance.[50]

Industries differ in their patent "consciousness" and practices. For example, the automotive industry (not R&D-intensive) does not aggressively seek patent positions, often patenting for defensive purposes. On the other hand, the chemical and pharmaceutical industries are highly patent-conscious, invest heavily in research and development, and depend on patent position to maintain a competitive edge. The electronics industry, while actively seeking patents, engages in extensive cross-licensing among firms. Patent protection is especially important to smaller innovative firms and individual entrepreneurs because of the protection afforded against copying by larger firms which can readily gain a more dominant market position.

The patent question can sometimes trouble the relationships between government and industry in R&D. Nearly all of the patented inventions owned by the federal government arise from the work of government contractors and employees. When government contracts for R&D, it may insist upon the rights to patent which may result from inventions paid for with public funds. The government may hold that if the contractor retains the right to an invention, he must license its use to others, including his competitors. When such restrictions are imposed, industry may refuse to compete for the government R&D contract. Government patent policies are not uniform. Some government agencies impose restrictive rules on patent ownership, even demanding access to background patents, while other agencies have more moderate policies, such as merely requiring that the government be given a license to the invention. Many industrial firms do business with the more liberal agencies while avoiding the others.[51] The allocation of rights to inventions is determined by each sponsoring department and agency in accord with the Presidential Statement on Government Patent Policy and the terms of specific legislation determining the disposition of patentable inventions (e.g., NASA, DOE among others).

The Presidential Policy Statement provides the flexibility, guidance and incentives needed to promote private investment in follow-up development and commercial application. The Statement recognizes such variables as the different missions of government agencies and of individual research programs and their widely varying ends, and the wide variety of contractors engaged in the research and development effort.

Generally speaking, the Policy Statement requires the government to take title to inventions where the research and development are in areas of public health, welfare, or safety, or where the research results are intended for use by the general public. However, "exceptional circumstances" are recognized. Where the research and development results are primarily intended for governmental use, the contractor may, at the time of contracting, retain patent rights if the invention is in a field where the contractor has a prior investment and commercial position. Safeguards are provided by requiring the contractor to license others if the contractor does not bring inventions into commercial use.

The Presidential Policy Statement also authorizes both exclusive and nonexclusive licensing of government-owned inventions. Nonexclusive, royalty-free licensing is preferred whenever this procedure will promote commercial use of inventions. However, exclusive rights for a limited time will be granted by the government when it appears that such an incentive is necessary to attract the investment of capital for technical and market development.[52]

For acquisition of inventions developed by government employees Executive Order 10096 provides for the establishment or a uniform patent policy among the various government agencies. The Executive Order directs that the government shall obtain the entire right, title and interest in all inventions made by any government employee:

1. During working hours

2. With government facilities, equipment, materials, funds, or information, or with the time or services of other government employees on official duty or

3. Bearing a direct relation to or made in consequence of the official duties of the inventor

Where the contribution of the government to the development of invention is insufficient to justify acquisition of title, the employee/inventor retains title.[53]

Argument about whether the government should grant exclusive licenses to patents it owns and controls brings into basic conflict a principle and a fact: the widely accepted principle that when technology has been acquired at public expense no citizen should be favored over any other and the well established fact that for a firm to commercialize technology successfully with significant benefits to society at large, it must have a period of exclusivity and proprietary advantage before an influx of competitors makes the infant business unprofitable. This period of exclusivity is particularly important for the smaller and less financially stable company.

In the past 20 years, several revisions have been proposed to improve the patent system. The U.S., of course, awards patents by an examination system to establish novelty and utility. This process can take several years. Moreover, many patents which are challenged in the courts are declared invalid because the challenger has found some sort of published material--"prior art"--which pre-dated the patent application and which was not properly considered by the examiner before the office awarded the patent. One proposed revision is some modification of the system in use in many Western European countries whereby the patent application is "published for opposition" to give other parties the right to challenge its originality by citing "prior art," thus speeding up the patenting process and making the issued patent considerably stronger. Whether such proposals for patent "reform" will succeed in the near future seems problematical.

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V THE DIFFUSION OF TECHNOLOGY

INTRODUCTION

Students of research management and technology utilization are increasingly concerned about our poor understanding of the processes by which technical information is communicated among segments of American society and appropriate technology made available and comprehensible to those who may be able to take advantage of it. Allen stresses the need for the potential user of the technology to play more than a passive role. The human factors in the process are of overriding importance. Donald Schon has observed that "the mere existence of a lot of technical information, data, or technology is no reason per se for spending money to get it used." He poses the question, "Do you concentrate on transferring technology that already exists or do you concentrate on working with problems that seem to require technological innovation?"[1] This chapter surveys the mechanisms by which scientific and technical information is communicated and describes industry's use of government research and transfer of technology, both nationally and internationally.

PUBLICATION OF SCIENTIFIC AND TECHNICAL INFORMATION

Professional Associations

The scientific and technical community includes many scientists and engineers in different fields. Those with the same problems and the same interests have grouped themselves into professional associations, e.g., the American Physical Society (APS),

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the American Medical Association (AMA), and the American Chemical Society (ACS). The American Association for the Advancement of Science (AAAS) is less specialized and is open to all scientists. Most of these organizations sponsor publications which keep their members and political and economic leaders informed. There are more than 1000 scientific and technical associations in America, and their considerable resources reflect the general prosperity of American science. Some conduct research and application in their own facilities, finance similar work outside, or are concerned with the standardization of specifications and test methods. By means of national and international meetings, special congresses, and publications, they encourage research. Increasingly, many of them are taking a public stand on scientific questions of national interest and advocating the cause of science.

The primary function of these associations is to represent the interests of their members. When the resources assigned to research and development are expanding, their participation in the political process can sometimes be incidental but substantive also.

In addition to professional and scientific associations, many industry and trade associations seek to inform their members, the users of their products, and the general technical community not only of R&D carried out under their auspices, but also about new technology of interest and benefit to industry. They publish journals, abstracts, and bulletins, and regularly hold technical meetings. In the energy field, most of the organizations mentioned earlier as vehicles for collaborative industry research such as API, BCR, AGA, and EPRI have formal programs to publish and disseminate their information.

Each society or association has a sphere of interest and activity, sometimes with emphasis on pure and applied science, and sometimes on commercial application of known technology. An engineer or scientist in the plastics industry, for example, may well turn to a publication of the American Chemical Society or the American Physical Society for fundamental studies of polymerization and polymer properties; to a publication of the Society for Plastics Engineers or the American Society of Rheology for information about how best to process a particular polymer on commercial equipment; and to the Society of Plastics Industry, a trade association, for information about where plastics are used, how to transport them most economically, how to surmount safety problems, and what government regulations affect their use.

The extraordinary expansion in scientific and technical research in the past half century has been reflected in a parallel expansion in the scientific press; the number of science journals throughout the world was estimated in 1963 at 35,000, of which 6200 (17.7%) were published in the United States; the total number throughout the world is estimated to double every 10 or 15 years.

A survey of 262 scientific journals was made by the National Science Foundation in 1960. The survey attests to the rapid development of this specialized press. This expansion reflects the general trend of American science but is also the result of the structure given to science policy. It is becoming important for researchers to publish their results if they wish to acquire the reputation and standing which to some extent guarantee the attention of their peers and of the government, upon whom, because of the panel system and project grants, the future of their work depends.

Most American science publications are therefore of recent creation; the average age of journals in the sample examined by NSF was 31 years.

The changes in government activities which have involved scientists in political concerns are reflected as well in these journals. The scientific press has come to interest itself in public affairs and to give them increasing space in its columns. The editorials and special feature articles of science journals are increasingly covering and analyzing science policy.

Information Services

No one comprehensive scientific and technical information service exists in the United States. Information services are provided by federal agencies, scientific and technical societies, and for-profit commercial firms. These services include the preparation and distribution of primary journals, critical reviews, and reference materials; operation of abstracting and indexing services; development and operation of numerical data banks; maintenance of information analysis centers, and computer-based searching and retrieval services, including networking arrangements; and operation of library and reference facilities. In all, several thousand organizations offer such services.

The federal government, through approximately 10 major departments and agencies, publishes a limited number of journals and other materials; supports the operation of agency or mission-oriented abstracting and indexing services; provides support, through research grants, for publication of journals by scientific and technical societies; provides most of the support for information analysis centers; and operates two national services--the Smithsonian Science Information Exchange, for retrieval of descriptions of ongoing work, and the National Technical Information Service, for retrieval of completed reports and sale of information analysis and computer tapes generated by federal agencies.

Scientific and technical societies publish most of the journals and some reference materials. They also operate discipline-based abstracting and indexing systems. Their annual conferences and other meetings and symposia provide important informal information exchange opportunities. Except for such professional journals, for-profit firms dominate publishing. Commercial firms produce most of the monographs, textbooks, handbooks, and reference materials. In recent years, for-profit firms have developed abstracting and indexing services. The Institute for Scientific Information in Philadelphia is a prime example. Commercial firms have also led in the development of nationwide, on-line searching of bibliographic data bases generated by federal and private organizations. In addition, state and local governments support libraries and information centers through funds provided to colleges and universities.

Science News

Science news plays a small part in the American press, although the national press does show a certain interest in science affairs. Science commentators on a few large newspapers and television channels enjoy considerable national prestige. They generally recognize that they have a twofold responsibility to inform the public about the development of science as such and to analyze the political aspects of this development.

DIFFUSION OF FEDERAL GOVERNMENT R&D

The diffusion of R&D sponsored by the federal government to private industry is generally held to be ineffective. Large sums of money have been spent over the past 15 years to promote utilization of developments stemming from the space program. The success of this effort in the view of most industrial research managers has been questionable, although there have been a number of notable specific achievements.

In contrast, the record of disseminating the results of agricultural research supported by the federal government is often cited as an outstanding success. Pearson argues that this system should be a model for similar efforts in disseminating technologies.[2]

He points out that agriculture has the best growth rate of all the major economic sectors in the U.S. in spite of a steady decline in the labor employed in farming. He attributes much of this success to the Cooperative Extension Service established over 100 years ago and operated by the nation's land-grant colleges to serve their regional agribusiness communities. The advisors are skilled agricultural experts who work directly with producers and processors in implementing the latest technologies.

Such programs are voluntary and do not violate American concepts of freedom of choice. For every dollar spent in agricultural research in the U.S. 50 cents is spent on its delivery to those who can use it. The figure for other areas of scholarly research is about one cent for each research dollar.

It is probably too simple to maintain that such a system could be applied to industry in general without significant modification since agriculture differs from manufacturing in user group homogeneity, proprietary competition, and capital requirements. Pearson, however, believes that some of the fundamental factors can be identified and applied.

Indeed, in the early 1970s the federal government, under the State Technical Services Act, set up and largely funded organizations in a number of states to provide technical information and assistance to local, usually small, businesses. After a few years, this program was discontinued as ineffective. However, a strong body of opinion exists that in many states these agencies performed a useful function and that the entire program was not given a fair trial.[3]

Recently other government organizations have been established specifically to foster improved diffusion of technology, particularly within NSF and NBS. These organizations are charged with improving the transfer function to state governments and industry. Their ultimate effectiveness remains to be seen since they are young.

The National Technical Information Service of the Department of Commerce also is becoming more effective in the area of transfer of government information and rights to government technological developments. It is now staffed with a number of managers broadly experienced in industrial research in the private sector. The problems inherent in a private firm's using a high-risk technology developed by the government have been discussed in the section on patents.

There seems to be some ambivalence as to whether technology developed in the United States should be made freely available to other nations. Such transfers obviously impact the national security and the economic well-being of the nation. There is no effective mechanism for fully assessing the impacts and results of such transfers, so this debate is expected to continue while methodological improvements are developed.

Diffusion in U.S. Industry

Diffusion of the results of basic research differs from that of applied research, development, and operating practices. Basic research is usually published and available to all. Applied research and development is usually closely held in the private sector and its transfer from firm to firm occurs generally after there has been some commercial realization of the results by those firms and individuals that hold proprietary rights. The most effective means of communication or transfer is informal or by movement of people.

U.S. industrial firms depend strongly on new technology in their efforts to maintain and improve their efficiency and profitability, and as a consequence they guard their new technology closely. The normal protection is to patent the useful new results of R&D. However, companies occasionally avoid the patent route and depend upon concealment.

Once a new product or process is patented, the industrial firm considers how best to exploit the patent. Almost invariably, the first consideration is whether the patent can be used by the firm itself. If a new product is implied, the decision as to whether to "go commercial" is the key decision. However, once the utility of the patent to the industrial firm has been analyzed in detail, it is normal to determine if additional revenue can be obtained from the patent by licensing it to other companies. Licensing is, in fact, a common procedure and represents a source of significant revenue to many companies. In some cases, patents will be licensed to firms which are directly competitive. For example, a petroleum company with a new refining process frequently finds it profitable, after installing the new process in its own refineries, to license the rights to the patents to its competitors.

New ideas and directions which are not patentable also spread widely across U.S. industry. One channel for dissemination of new ideas is the equipment makers who sell improved equipment to interested buyers. Another is the numerous engineering and management consulting firms.

As has already been noted, some corporations successfully make the acquisition of technology from outside the firm an integral part of their R&D and corporate growth program, especially if it is cheaper and faster to purchase another firm's "know-how" than to replicate it.[4] Gold has concluded that one factor favoring this strategy is that companies tend to license their technology to others for fees which probably represent less than what the technology is truly worth. Many corporate managers, given the opportunity to license some new technology to others, opt for the quick return provided by the initial payment and the running royalties, instead of holding out for the much slower penetration of new markets and geographical areas if the company exploited the technology on its own, which would most likely be more profitable in the long run.[5] A program of acquiring outside technology can rarely succeed, however, unless the acquiring company has excellent technical capabilities of its own to adapt the developments to its particular needs.

Mansfield estimates that it takes on the average about eight years for half the major firms in an industry to begin using an important innovation.[6] This figure varies: 15 years for half the pig-iron producers to use the by-product coke oven, but only three years for half the coal producers to begin using continuous mining machines. It took nine years, on the average, for an American railroad to go from 10% to 90% replacement of steam locomotives with diesel.[7] In any country, the important qualitative factors appear to be:

> The health of a nation's scientific and technological establishment
>
> The quality of its education system
>
> The supply of better educated and younger managers, who tend to adopt new technology more quickly

There is no evidence that the stage of the business cycle is a major influence, i.e., no tendency for the introduction of new technology to "cluster" in prosperous or poor times for a firm.[8]

There must be a "threshold size" in the firm, but very large companies are no more apt to introduce new technologies than medium-sized ones. Smaller firms tend to be quicker to substitute a technology than larger firms, probably because of their

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homogeneity and fewer decision-making centers. Furthermore, there is no evidence that highly concentrated industries are quicker to introduce new technologies. There is also little hard evidence about the effect of a firm's organizational structure on its ability to adopt new technology, but companies without a number of layers of management seem to be more likely to innovate.

Mansfield has developed a formula which relates with reasonable accuracy the probability of a company's adopting an innovation from outside to the proportion of firms in the industry which are already using it, the profitability of introducing it, and the investment required to install it expressed as a percentage of the firm's assets.

Although government policies probably have some influence on the diffusion of technology in the economy, the degree of influence is by no means clearly defined. Perhaps most important is maintaining an educational establishment which produces well-trained technologists and managers. The maintainence of a competitive environment may possibly be a factor.

International Diffusion

Multinational transfers occur in a number of ways. Technology may be transferred through international agreements or conferences; it may be transferred through dissemination of publications; or it may occur through simple, informal, interpersonal contacts.[9]

Transfers may also be the result of the licensing of U.S. technology to foreign firms. This is most likely to occur where the host country severely restricts imports and exports. Because the U.S. firm loses control over the licensed technology, the larger companies are generally reluctant to select this method unless other alternatives seem too costly. Smaller companies, on the other hand, are more willing to license technology to unaffiliated companies.

Transfers also may simply result from the introduction of new products and processes into other economies. In order to do this efficiently, it is often necessary for the U.S. parent organization to export equipment to the international affiliate and to train a local staff in the newest methods and techniques used by the U.S. company.

An obvious form of technology transfer is when the parent company engages in research and development activities abroad. When R&D is undertaken, scientists and engineers are either transferred from the U.S. parent company, or a foreign staff is trained to perform R&D functions, or both. The variations upon these possibilities result in the actual transfer of widely differing amounts of technology. The foreign affiliate may, in some cases, perform the most routine mechanical and clerical functions; in other cases, the knowledge and skills of the foreign nationals may eventually work their way into the economy of the host country. When the latter occurs, the newly gained knowledge and research techniques may be put to other uses and to devising new technology to further economic growth. This is the hoped-for gain over the longer term from technology transfer from one country to another.[10]

INTERCHANGE OF RESEARCH MANAGEMENT TECHNIQUES

As research management has become an increasingly important branch of the management profession, a number of organizations have been established to facilitate exchange of opinions and information about successful research management methods among active R&D managers. Regional "Research Directors Societies" exist in New York, Philadelphia, Boston, and Chicago.

The largest organization devoted to improving the management of research is probably the Industrial Research Institute (IRI) established in 1938 under the auspices of the National Research Council. The membership of IRI is over 240 companies which, it is believed, perform over 80% of the privately supported R&D in the country. IRI promotes relationships involving applied science and technology among industry, the universities, and the federal government. It is sometimes asked to provide advice to government departments and to committees of Congress about expected impacts of present and proposed government policies and legislation.

In 1975, IRI set up the Industrial Research Institute Research Corporation as a mechanism to monitor and supervise studies on research management. Funds for these studies usually come from the federal government.

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VI SOME IMPORTANT ISSUES IN AMERICAN R&D

INTRODUCTION

In considering problems facing United States science and technology one must not be overly influenced by what may well be short-term trends. For example, is the 6% decline in employment of engineers and scientists in industrial research since 1969 counterbalanced by the modest rise in such employment over the past few years, with almost all the increase supported by private firms?[1] The share of U.S. patents issued to foreign residents has more than doubled in 15 years to the current level of 35% of the total. Is this a matter for concern in view of the fact that many other countries 15 years ago were still recovering from World War II and the U.S. is now maintaining a favorable balance of patents with the major industrial countries?[2]

In spite of the problems of interpreting such indicators, there is a rather broad concensus that American technological leadership may be eroding. For example, a recent study of the production of patents and publications by the 12 largest chemical companies shows a decrease of 40% over the period 1966-1977 while R&D expenditures, expressed in constant dollars, were actually increasing by about that same proportion during those years.[3]

There seems to be little evidence, based upon public opinion polls, that the American people are significantly disenchanted with science and tech-

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nology and what they can contribute to solving the problems of our complex society.[4] But the scientific community in general will have to adapt to a changed environment if it is to retain the respect accorded it by the public. One problem so obvious that it is often overlooked is that the rate of technological advancement of the kind which can readily be understood by society as clearly beneficial may be declining simply because what is easy has already been done. In medicine, the death rate decreased drastically during the first half of the century because of improved sanitation, the elimination of many childhood diseases, and the successful treatment of bacterial infections. Against this background, progress in treating cancer, heart disease, and the degenerative diseases seems painfully slow. Another example: the great expansion of the petro-chemical industry in the period 1940-1960 was achieved by straightforward engineering applications of fundamental chemistry known for many years before. Few major new household appliances have been introduced in recent years and it is unlikely that totally new synthetic fibers will be commercialized.

The following discussion touches on a few of the issues which must be dealt with and which raise questions which have no simple answers.

ORGANIZATION OF RESEARCH IN THE FEDERAL GOVERNMENT

In a fairly regular cycle, proposals are seriously advanced for a much greater degree of centralization and coordination of R&D in the federal government. After World War II serious consideration was given to establishing a Cabinet level Department of Science and Technology. In 1969 Congressional hearings were held about establishing National Institutes of Research and Advanced Studies, which would fund almost all federally administered basic research and graduate education. One principal justification for such a centralized agency would be that it could provide better continuity of financial support for the nation's important basic research efforts.[5]

The many organizations in the government concerned with energy research were in fact centralized in ERDA (since transferred to the new DOE). By and large, however, there seems to be no strong groundswell for major centralization at this time. Although there is, of course, risk of duplication of effort, there is widespread fear that establishing a monolithic bureaucracy to administer all the government's research would be counterproductive. Having diverse sources of funding may, many feel, be beneficial for those who rely on government support for their work.

Along with proposals for a more centralized and better coordinated federal R&D effort, suggestions for a formalized system of overall long-range R&D planning crop up continuously. Obviously some long-range planning is critically important at the level of the agency and the program manager. But whether there can be a "rational plan for R&D" which would be more than a set of gross extrapolations or a pious "wish list" is questionable.

All R&D plans either in macro- or micro-scale depend on assumptions about probabilities of success in the R&D. It is difficult in the research culture to incorporate negative events in such a plan. At what phase in such planning must the unavoidable financial constraints be taken into account?

This in turn raises the question of who does the planning. The research community would be unhappy to see such a planning body dominated by nontechnical people, but it is such people who will be largely responsible both for saying what goals are worthwhile and what resources can be provided.

The most cogent negative argument, however, is the fact that such a structured and formal environment would act, perhaps only in subtle ways, to discourage the unconventional, the radically new, and the currently out-of-fashion creative thrusts which history has shown so important for the nation. At present, review of R&D decisions by higher government authorities normally is limited to budget questions and to rationales for the total R&D program, and only rarely does a higher authority review a specific project.[6]

THE PAY-OFF FROM R&D

Several efforts have been made to show that technological innovation derives from basic research. Unfortunately, it seems that many investigators arrive at the answer which accords with their own predilections. In fact, there is much evidence that useful technology builds to a great extent on earlier technology. Certainly, however, the bulk of the evidence indicates a positive relationship between the health of the nation's basic research endeavor and its ultimate success in technological innovation. An NSF study of 10 important innovations carefully traced the essential research events and highlighted the contributions of basic research. It also demonstrated the lengthy time periods involved. The average time from first product conception to commercial application was about 19 years. Half the basic research "events" took place 30 years before commercialization. Thus, it is extremely difficult to relate with any precision the contribution of any one basic research program to an identified commercial objective.[7]

Nor is there strong evidence that government spending for basic and applied science has any rapid pay-off in improved productivity and economic growth. Participants in a recent NSF symposium were conservative about crediting government R&D

funding for anything more than a marginal contribution to the nation's economy.[8]

In industrial research, Mansfield has studied in detail a small sample of specific R&D programs aimed at technological innovation. He distinguishes between the "social rate of return" to the society as a whole and the "private rate of return" to the particular firm. The median social return is 56% versus the median private return of 25% (see Table 7-1)[9] Thus, the pay-off from these projects to the economy appears high, whereas the pay-off for the company is nominal. In fact, managements of most corporations can find many investments which show promise of yielding 25% before tax at a much lower risk than investing in R&D or its exploitation. Even leading business publications are criticizing the senior managements of American companies for their increasing conservatism about undertaking R&D programs with a high degree of novelty.[10] In American business, management performance is judged by shareholders and the investing community on a much shorter time scale than corresponds to the period required to bring an entirely new technology to commercialization.[11] Furthermore, the correlation between R&D expenditures and company growth and profitability has been found to be fairly weak in recent years.

PROBLEMS OF THE UNIVERSITIES

After undergoing great expansion during the postwar years the universities are now faced with declining enrollments partly because of decreases in the birth rate and partly because many young people are finding the financial return on a university education to be not as great as it was. Reduced income from student fees, along with inflationary pressures, are causing serious budgetary problems in public and private institutions. Few new faculty members are being added, and in many universities

TABLE 6-1

INVESTMENT RETURNS FROM R&D CAN DIFFER SHARPLY

INNOVATION	RATE OF RETURN SOCIAL	RATE OF RETURN PRIVATE
Primary metal innovation	17%	18%
Machine tool innovation	83	35
Component for control system	29	7
Construction material	96	9
Drilling material	54	16
Drafting innovation	92	47
Paper innovation	82	42
Thread innovation	307	27
Door control innovation	27	37
New electronic device	Negative	Negative
Chemical product innovation	71	9
Chemical process innovation	32	25
Chemical process innovation	13	4
Major chemical process innovation	56	31
Household cleaning device	209	214
Stain remover	116	4
Dishwashing liquid	45	46
MEDIAN	56%	25%

Source: Edwin A. Mansfield

the prospects for a junior faculty member's attaining a tenured appointment are bleak. Another possible problem, already mentioned, is that research faculty seeking government and industry support may undertake projects in applied research not entirely suitable to their own aptitudes and to the missions of their universities. The Industrial Research Institute is on record as supporting adequate government funding of basic research in the universities which it regards as the field in which they can make their maximum contributions.

GOVERNMENT REGULATION AS A BARRIER TO INNOVATION

In two industries, pharmaceuticals and agricultural chemicals, a number of studies have shown fairly conclusively that product introduction has drastically slowed since increasingly stringent government regulations have come into effect during the past 15 years.[12] In pharmaceuticals, as an example, there has been a shift of dollars from basic research to development, an increase in the critical mass of people and funds to undertake a major research project, a decrease in the number of research projects, and a change to project-oriented research organizations.[13] It must be admitted, however, that these two industries deal with products deliberately designed to have biological activity. There is little doubt that the American public is fearful--although perhaps excessively so --about the ingestion of any products which may have harmful side effects or the introduction of such products into the food chain. There is less evidence that the rate of innovation has been reduced in other industries subject to some form of regulation, although there is no question that the proportion of industrial expenditures devoted to meeting government requirements has grown rapidly, often at the expense of pioneering research.

Schweitzer recently studied the impact on the organic chemical industry of the Toxic Substances Control Act. This Act aims to prevent the introduction of materials which might be at all harmful to the environment or to worker safety. It has already caused a pronounced shift from offensive to defensive R&D in the companies affected. Perhaps more serious may be the attitudinal changes in the people involved in the research who, it appears, are becoming excessively cautious about even proposing projects to develop completely new products. The effect on small companies may be particularly unfortunate since these do not have the resources both to comply with complex government regulation and to undertake substantial new product development efforts.[14]

Obviously it would be most desirable to have better mechanisms to predict the long-term effects of proposed legislation and regulations on industrial innovation. A few government agencies are considering new approaches to achieving a better balance between risk and benefit. The Food and Drug Administration has proposed to permit important new pharmaceuticals to be introduced to the market without such lengthy testing as in the past provided that it is authorized to withdraw such products swiftly if there are reports of unexpected side effects resulting from their widespread use.

THE ROLE OF GOVERNMENT IN PRIVATE SECTOR R&D

There is, of course, a real question of whether government can or should undertake programs for the direct encouragement of an increased R&D effort in the private sector, either by positive actions or by reversing certain measures it may have taken earlier which may have depressed technological innovation. Certain trends are clear, however, which may justify government intervention:

> As cited above, Mansfield has presented impressive evidence that the average corporation may not be able to recoup the investments it has made in R&D although the economy has benefited handsomely.
>
> There seems little doubt that the United States has made an inordinately high investment in a few areas of science and technology, particularly space, defense, and atomic energy, as opposed to investment in technology whose benefits will accrue primarily to the civilian economy. Government action might perhaps redress this balance.[15]
>
> The formation of new high-technology companies which have contributed much to the American economy has diminished drastically in the past decade. From 1969 through 1974 the annual rate at which such companies were created diminished from about 200 per year to less than 25 per year. (In 1977 public funding for all new companies was on the order of $100 million as compared to $1.5 billion in 1969.)[16] Not only have such companies been responsible for valuable new technology which has diffused throughout the economy, but they have also created a disproportionately high number of jobs. Morse and Flender have analyzed job creation in mature companies, innovative companies, and young high-technology companies. From 1969-1974 the average annual percentage growth rate of these groups of companies in job creation was 0.6% for the mature companies, 4.3% for the established innovative companies, and 40.7% for the young high-technology companies.[17]

The question is: what is the government to do? Little will be gained by selecting a problem area and "throwing money at it." Nason has cautioned about rashly embarking on programs of government stimulation of research in the private sector without defining the objectives with precision and carefully considering all the side effects.[18]

A number of measures for government action have been proposed and are being given more or less serious consideration, among them:

1. Setting up a government agency to supply venture capital for new high-technology enterprises

2. Establishing some American counterpart Britain's National Research Development Corporation, which funds the development of inventions from universities, government laboratories, and small companies

3. Permitting companies to take special deductions for their R&D expenses against their taxes

4. Lowering taxes on the capital gains for those who acquire "founders stock" in new high-technology companies

5. Funding research--possibly in the national laboratories--for industries which are technologically weak

6. Reducing the time required to obtain new government contracts and the appalling complexities of government contract negotiations where truly novel technology is involved

7. Allowing for more "sole-source" contracts for firms who approach the government with innovative solutions to major problems

8. Loaning small companies government money to carry out the requisite investigations which will permit them to comply with govern-

ment regulations when a significant innovation is involved

All these, and a number of other proposals, have their proponents and may be worthy of consideration. Problems inevitably arise in the trade-off in equity versus efficiency.

In 1978 the President ordered a comprehensive study of innovation in the United States with a view to proposing measures which might enhance its effectiveness and its impact on the economy. This study, in which the leading role will be played by DOC, will almost certainly address many of the issues which have been discussed in this chapter.

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